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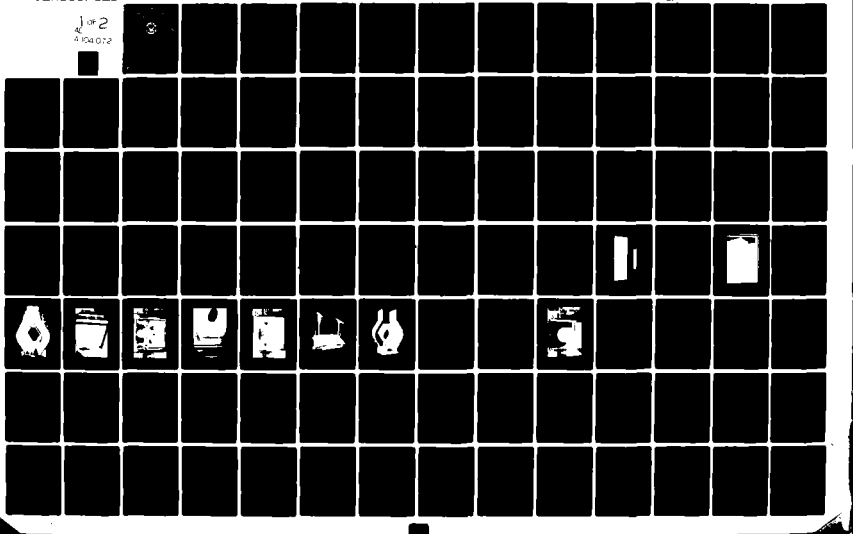

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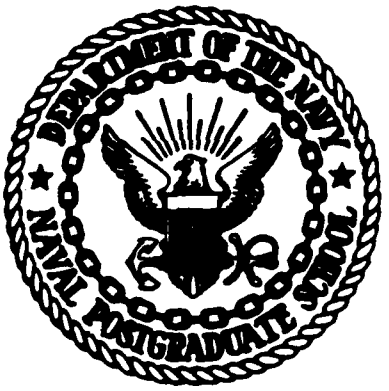


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# THESIS

FLOW CHARACTERISTICS OF A MULTIPLE NOZZLE EXHAUST GAS EDUCTOR SYSTEM

by

Dennis Leo Ryan III

March 1981

Thesis Advisor: P.F. Pucci

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Cold flow tests of a four nozzle eductor system were conducted to evaluate the flow characteristics of several mixing stack configurations. A previously tested mixing stack design used a plug to shield the primary flow nozzles from view. Flow visualization was used to determine the flow pattern in the stack. The results of the visualization runs were then used to modify the mixing stack geometry. The eductor system flow characteristics were evaluated

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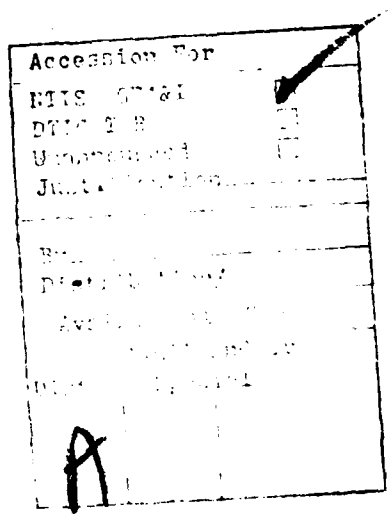

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# Flow Characteristics of a Multiple Nozzle Exhaust Gas Eductor System

by

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Submitted in partial fulfillment for the requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

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## ABSTRACT

Cold flow tests of a four nozzle eductor system were conducted to evaluate the flow characteristics of several mixing stack configurations. A previously tested mixing stack design used a plug to shield the primary flow nozzles from view. Flow visualization was used to determine the flow pattern in the stack. The results of the visualization runs were then used to modify the mixing stack geometry. The eductor system flow characteristics were evaluated in terms of non-dimensional parameters governing the flow phenomena from a one dimensional analysis of a simple eductor system. The eductor system's pumping capacity was improved over that of the previously tested unmodified mixing stack.

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## NOMENCLATURE

### English Letter Symbols

| | | |
|---|---|---|
| A | - | Area, $in.^2$ |
| c | - | Sonic velocity, ft/sec |
| C | - | Coefficient of discharge |
| D | - | Diameter, in. |
| $F_a$ | - | Thermal expansion factor |
| $F_{fr}$ | - | Wall skin-friction force, lbf |
| $g_c$ | - | Proportionality factor in Newton's Second Law, $g_c$ = 32.174 lbm-ft/lbf-$sec^2$ |
| h | - | Enthalpy, Btu/lbm |
| k | - | Ratio of specific heats |
| L | - | Length, in. |
| P | - | Pressure, in. $H_2O$ |
| $P_a$ | - | Atmospheric pressure, in. Hg |
| $P_v$ | - | Velocity head, in. $H_2O$ |
| PMS | - | Static pressure along length of mixing stack in. $H_2O$ |
| R | - | Gas constant for air, 53.34 ft-lbf/lbm-R |
| s | - | Entropy, Btu/lbm-R |
| S | - | Primary dimension of mixing stack |
| T | - | Absolute temperature, R |
| u | - | Internal energy, Btu/lbm |
| U | - | Velocity, ft/sec |

| | | |
|---|---|---|
| $v$ | - | Specific volume, $ft^3/lbm$ |
| W | - | Mass flow rate, lbm/sec |
| D | - | Distance from primary nozzle exit to mixing stack, in. |
| Y | - | Expansion factor |

Dimensionless Groupings

| | | |
|---|---|---|
| A* | - | Secondary flow area to primary flow area ratio |
| AR | - | Area ratio |
| f | - | Friction factor |
| K | - | Flow coefficient |
| $K_e$ | - | Kinetic energy correction factor |
| $K_m$ | - | Momentum correction factor at the mixing stack exit |
| $K_p$ | - | Momentum correction factor at the primary nozzle exit |
| M | - | Mach number |
| $\Delta P^* = P^*$ | - | Pressure coefficient |
| PMS* | - | Mixing stack pressure coefficient |
| Re | - | Reynolds number |
| D/S | - | Standoff; Ratio of distance from primary nozzles to entrance of mixing stack, (D) to primary dimension of mixing stack (S) |
| T* | - | Absolute temperature ratio of the secondary flow to primary flow |
| $T_t^* = TT^*$ | - | Absolute temperature ratio of the tertiary flow to primary flow |
| $W^* = W^*$ | - | Secondary mass flow rate to primary mass flow rate ratio |

$W_t^* = WT^*$ - Tertiary mass flow rate to primary mass flow rate ratio

L/S - Ratio of distance from entrance of mixing stack to diameter of mixing stack

$\sigma^*$ - Induced flow density to primary flow density

Greek Letter Symbols

$\mu$ - Absolute viscosity, $lbf\text{-}sec/ft^2$

$\rho$ - Density, $lbm/ft^3$

Subscripts

0 - Section within secondary air plenum

1 - Section at primary nozzle exit

2 - Section at mixing stack exit

f - Film or wall cooling

m - Mixed flow or mixing stack

or - Orifice

p - Primary

s - Secondary

t - Tertiary (Cooling)

u - Uptake

w - Mixing stack inside wall

Computer Tabulated Data and Illustrative Plots

UPTMACH - Uptake Mach number

PA-PS - Static pressure at mixing stack entrance, in. $H_2O$

PA-PT - Static pressure in tertiary air plenum, in. $H_2O$

# I. INTRODUCTION

With gas turbines becoming a more popular means of powering naval vessels, special considerations need to be given to their particular air breathing and exhausting characteristics. With air-fuel ratios of four to five times that of conventional steam plants and the requirement for a relatively large amount of combustion air, a large quantity of hot exhaust gas is generated. Due to gas turbine design, these exhaust gases are a temperatures significantly above those of conventionally powered ships. A few of the problems caused by these high temperatures are thermal damage to electronic equipment located on the masts of these ships, hot gas corrosion of masts and other superstructures located in the hot gas wake, and a significant infrared radiation signature created by the hot gas plume and hot external surfaces of the stack.

This thesis is an extension of research done by Ellin [Ref. 1], Moss [Ref. 2], Lemke and Staehli [Ref. 7], and Shaw [Ref. 8] to determine better geometric designs for the exhaust plenum and mixing stack system of gas turbine powered naval ships.

Ellin initiated the work by constructing an eductor model testing facility consisting of an uptake, primary flow nozzle, mixing stack, a means to control and measure the primary air flow, and a means to measure the secondary air flow; see

Figures 1 and 2. The primary air flow in the testing facility represents a gas turbine's hot exhaust gas. The secondary air flow is ambient air induced into the entrance of the mixing stack by the primary air flow; see Figure 3. From Ellin's study of multiple nozzle flow systems consisting of several identical round nozzles, it was determined that four primary flow nozzles were preferable to either three or five, and that nozzle length has little or no effect on the eductor system's overall performance. Ellin then verified the independence of the one-dimensional model correlation parameters used on flow rate or Mach number. He determined that for Mach numbers from 50% to 145% of the design Mach number of 0.064, the correlation parameters suggested in the one-dimensional analysis did in fact provide a good correlation of the data.

Moss' work followed, and it initially consisted of verifying the one-dimensional analysis as did Ellin. He then tested the effect of the stand-off distance (that distance between the exit plane of the primary flow nozzles and the entrance plane of the mixing stack). For the primary flow nozzles he tested, Moss determined that the optimum stand-off distance for maximum eductor pumping was a distance equal to 0.5 diameters ($0.5D_m$) of the mixing stack. An independent investigation of this, conducted by Harrel [Ref. 3], confirmed Moss' findings. Moss then investigated the effects of a conical transition placed on the entrance to the mixing stack.

He concluded that a straight mixing stack without an entrance transition provided a better system performance.

The study conducted by Lemke and Staehli [Ref. 7] investigated the effects on the eductor system's overall performance of varying the geometric configuration of the mixing stack and changing the area of the primary flow nozzles. Their work showed that a decrease in the ratio of the area of the mixing stack to primary flow nozzles from 3.0 to 2.5 decreased uptake back pressure but reduced the pumping coefficient of the eductor. Lemke and Staehli then investigated the effects of a solid diffusor, a two-ring and a three-ring diffuser. The results of these tests showed a decrease in uptake back pressure and a improvement in the eductor's pumping capacity. They then performed tests on a ported mixing stack. Their work determined that significant air flow through the ports could provide film cooling on the inside of the mixing stack. To enhance the film cooling provided by the ported mixing stack, Lemke and Staehli placed a shroud around the mixing stack. This shroud did not degrade the pumping or mixing characteristics, yet it provided thermal shielding of the mixing stack. Their final configuration was a combination of the ported mixing stack with flow through shroud and diffusor. Lemke and Staehli concluded that this geometric configuration, combined with a ratio of the area of the mixing stack to the primary flow nozzles 3.0, provided the best system overall performance.

The work done by Shaw [Ref. 8] concentrated on a method to further reduce the infrared signature of the mixing stack. Of particular concern was the concealment of the hot primary flow nozzles from an overhead view. Using the results of Lemke and Staehli, Shaw designed a rectangular mixing stack with an internal symmetric plug, Figure 4. The internal plug, which shields the primary nozzles from direct view, is cooled by two means. The plug was ported, to provide film cooling along the exhaust gas side of the device. Also, the plug was shrouded (on the non-exhaust gas side) to direct the flow of cooling air to the ports and provide a means of convectively cooling the downstream half of the plug, see Figure 5. Shaw found that the rectangular mixing stack with plug increased the system back pressure and reduced the pumping capacity of the eductor. He also determined that the design and placement of the plug improved mixing of the exhaust gases with the secondary cooling air and that the plug provided a potential means of presenting a cool surface to view.

Based upon the conclusions and recommendations of Shaw, it was decided that geometric changes in the eductor should be investigated in order to lessen the penalties involved with plug installation. These changes will be described in detail in Section IV.

Evaluation of eductor system performance was measured in four areas: the amount of secondary air flow induced by the primary air flow, the degree of mixing of primary and induced

air flows within the mixing stack system, the amount of uptake back pressure impressed upon the turbine exhaust by the eductor system, and the amount of wall cooling air available to reduce the exterior stack temperature of the eductor system. Additionally, a qualitative indication of the flow patterns in the mixing stack was obtained through flow visualization.

The key factor which allows cold flow testing to predict the effects of a hot gas eductor system is the similarity of the momentum and energy transfer mechanisms in turbulent flows.

## II. EDUCTOR ANALYSIS

This investigation, being an extension of the work of Shaw [Ref. 8], and others [Ref. 1, 2, and 7]; uses the same one-dimensional analysis to model the eductor system. This one-dimensional analysis is given in Appendix A. As a result of this analysis, dimensionless parameters controlling the phenomena are obtained which are then used in the correlation of experimental data. Three such dimensionless groups used are:

$$\Delta P^* = \frac{P_a - P_{os}}{\frac{\rho_s U_p^2}{2g_c}}$$

a pressure coefficient which compares the pumped head $P_a - P_{os}$ to the driving head $U_p^2$ of the primary flow

$$W^* = \frac{W_s}{W_p}$$

a flow rate ratio, secondary to primary mass flow rate

$$T^* = \frac{T_s}{T_p}$$

an absolute temperature ratio, secondary to primary

## III. EXPERIMENTAL CORRELATION

For the geometries and flow rates investigated, it was confirmed by Ellin and Moss that a satisfactory correlation of the variables P*, T*, and W* takes the form

$$\frac{\Delta P^*}{T^*} = \emptyset(W^* T^{*n}) \qquad (1)$$

where the exponent n is determined to be equal to 0.44. The details of the determination of 0.44 as the correlating exponent for the geometric parameters of the models tested is given in Reference [1]. To obtain an eductor model's pumping characteristic curve, the experimental data is correlated and analyzed using equation (1) that is $P^*/T^*$ is plotted as a function of $W^* T^{*0.44}$. This correlation is used to predict the open to the environment operating point. Variations in the eductor model's geometry will change the appearance of the pumping ability between models. For ease of discussion, $W^* T^{*0.44}$ will henceforth be referred to as the pumping coefficient. Similarly, $WT^* TT^{*0.44}$ will be referred to as the film cooling or tertiary pumping coefficient.

## IV. MODEL GEOMETRIES

The multiple nozzle eductor systems studied here are designed specifically for service onboard gas turbine powered ships. The model consisted of a single primary uptake, a single cluster of four primary nozzles of constant cross section, and a mixing stack.

### A. MIXING STACK WITH PORTED AND SHROUDED PLUG

The eductor mixing stack as designed by Shaw with its tertiary air flow cooling ports and associated plug shrouding provided the base design for the initiation of this study. Shaw's design utilized a symmetric plug to shield the hot primary exhaust nozzles from direct view. The initial design by Shaw is illustrated in Figure 4. He then provided two means of cooling the surfaces of the plug that were exposed to direct view. The first method provides film cooling along both sides of the downstream half of the plug. The film cooling air is induced through three sets of ports located as illustrated in Figure 5. The dimensional configuration of the ports is shown in Figure 6. The second means of cooling the plug provides an air flow to convectively cool the downstream half of the plug. This is accomplished with a shroud that directs a flow of air along the backside of the plug before it is pulled through the ports to be used

for film cooling. This flow of air is called tertiary air flow and is illustrated in Figure 5.

B. CUSP MODIFICATION OF THE PLUG

The symmetric design of the plug was modified by the addition of a cusp on the exhaust gas inlet side in order to provide a more uniform and gradual direction of the gas flow about the plug and to physically separate the flow into two symmetric parts. The cusp addition is picture in Figures 7 and 9 and dimensionally illustrated in Figure 8. The cusp was manufactured from 0.102 cm (0.04 in) thick sheet aluminum. Each side of the cusp was formed to a concave shape with a 24.77 cm (9.75 in) radius of curvature. Axial supports were soldered on the inside of the cusp to prevent warpage. The cusp was then glued over the inlet end of the plug. The apex of the cusp was aligned on the cross-sectional center-line of the mixing stack to maintain symmetry of the flow about each half of the mixing stack. The apex of the cusp extended upstream toward the entrance of mixing stack 7.11 cm (2.8 in) along the axial centerline from the end of the plug. The lip formed where the edges of the cusp met the plug was filled in with putty to provide a smooth surface. The corners between the cusp and the sides of the mixing stack were sealed with silicone epoxy to minimize leakage.

C. MIXING STACK SIDE MODIFICATION

The second geometric modification to Shaw's design changed the shape of the curved sides of the mixing stack. In Shaw's original design, at the position where the two air flows around the plug reconverged, the sides of the mixing stack had a 137 degree angle bend into the final exit duct portion (see Figure 5). This point was 48.59 cm (19.13 in) from the entrance of the stack. This sharp corner was removed from the stack by installing a curved side beginning at a point 43.18 cm (17.0 in) from the stack entrance. The radius of curvature of the new piece was 43.18 cm (17 in). The new sides were also made of .102 cm (.04 in) sheet aluminum. Edges formed where the new section was fitted into the mixing stack were filled in with putty to maintain a smooth surface. The mixing stack with the side modification is dimensionally shown in Figure 10. The picture in Figure 11 highlights the area changed by the side modification and cusp addition.

## V. EXPERIMENTAL FACILITY

Air is supplied to the primary nozzles by means of a centrifugal compressor and associated ducting schematically illustrated in Figure 1. The mixing stack configuration being tested is placed inside an air plenum containing an airtight partition so that two separate air flows, secondary and tertiary, may be measured. The air plenum facilitates the accurate measurement of secondary and tertiary air flows by using ASME long radius flow nozzles.

### A. PRIMARY AIR SYSTEM

The circled numbers found in this section refer to locations on Figure 1. The primary air ducting is constructed of 16-gage steel with 0.635 cm (0.25 in) thick steel flanges. The ducting sections were assembled using 0.635 cm (0.25 in) bolts with air drying silicone rubber seals between the flanges of adjacent sections. Entrance to the inlet ducting (1) is from the exterior of the building through a 91.44 cm (3.0 ft) square to a 30.48 cm (1.0 ft) square reducer, each side of which has the curvature of a quarter ellipse. A transition section (2) then changes the 30.48 cm (1.0 ft) square section to a 35.31 cm (13.90 in) diameter circular section (3) . This circular section runs approximately 9.14 m (30 ft) to the centrefugal compressor inlet.

A standard ASME square edged orifice (4) is located 15 diameters downstream of the entrance reducer and 11 diameters upstream of the centrifugal compressor inlet, thus insuring stability of flow at both the orifice and compressor inlet. Piezometer rings (5) are located one diameter upstream and one-half diameter downstream of the orifice. The duct section also contains a thermocouple just downstream of the orifice. Primary flow is measured by means of the standard ASME square edged orifice designed to the specifications given in the ASME power test code [Ref. 5]. The 17.55 cm (6.902 in) diameter orifice used was constructed out of 304 stainless steel 0.635 cm (0.25 in) thick. The inside diameter of the duct at the orifice is 35.31 cm (13.90 in) which yields a beta ($\beta = d/D$) of 0.497. The orifice diameter was chosen to give the best performance in regard to pressure drop and pressure loss across the orifice for the primary air flow rate used (1.71 Kg/sec (3.77 lbm/sec)).

The centrifugal compressor 7 used to provide primary air to the system is a Spencer Turbo Compressor, catalogue number 25100-H, rated at 6000 cfm at 2.5 psi back pressure. The compressor is driven by a three phase, 440 volt, 100 horsepower motor.

A manually operated sliding plate variable orifice (6) was designed to constrict the flow symmetrically and facilitate fine control of the primary air flow. During operation, the butterfly valve (8) , located at the compressor's

discharge, provided adequate regulation of primary air flow, eliminating the necessity of using the sliding plate valve. The sliding plate valve was positioned in the wide-open position for all data runs.

On the compressor discharge side, immediately downstream of the butterfly valve, is a round to square transition (9) followed by a 90 degree elbow (10) and a straight section of duct. All ducting to this point is considered part of the fixed primary air supply system. A transition section is fitted to this last square section which reduces the duct cross section to a circular section 29.72 cm (11.17 in) in diameter. This circular ducting tapers down to a diameter of 26.30 cm (11.5 in) to provide the primary air inlet to the eductor system being tested. The transition is located far enough upstream of the model to insure that the flow reaching the model is fully developed.

B. SECONDARY AIR PLENUM

The secondary air plenum, pictured in Figure 1 and 2, is constructed of 1.905 cm (0.75 in) plywood and measures 1.22 m by 1.22 m by 1.88 m (4 ft by 4 ft by 6.17 ft). It serves as an enclosure that can contain all or only part of the eductor model and still allow the exit plane of the mixing stack to protrude. The purpose of the secondary air plenum is to serve as a boundary through which secondary air for the eductor system must flow. Long radius ASME flow nozzles,

designed in accordance with ASME power test codes [Ref. 5] and constructed of fiberglass, penetrate the secondary air plenum, thereby providing the sole means for metering the secondary air reaching the eductor. Appendix D of Reference [1] outlines the design and construction of the secondary air flow nozzles. By measuring the temperature of the air entering and the pressure differential across the ASME flow nozzles, the mass flow rate of secondary air can be determined. Flexibility is provided in measurement of the mass flow rate of secondary air by employing flow nozzles with three different throat diameters: 20.32 cm (8 in), 10.16 cm (4 in), and 5.08 cm (2 in). By using a combination of flow nozzles, a wide variety of secondary cross sectional areas can be obtained.

A secondary air flow straightener, shown in Figures 1 and 2, consisting of a double screen is installed 1.22 m (4 ft) from the open end of the secondary air plenum, between the ASME long radius nozzles and the primary air flow nozzles. The purpose of the straightener is to reduce any swirl effect that could result when only a small secondary air flow area exists.

## C. TERTIARY AIR PLENUM

The tertiary air plenum, pictured in Figures 12 and 13, is constructed of 1.90 cm (0.75 in) plywood and measure 1.22 m by 1.22 m by 1.22 m (4ft by 4 ft by 4 ft). It serves as

an enclosure that completely surrounds the mixing stack and allows the exit and entrance regions to protrude. An air-tight rubber diaphragm type seal, schematically illustrated in Figure 2 and pictured in Figures 14 and 15, is located at each end of the enclosure. This allows measurement of a tertiary air flow independent of the secondary air flow. Tertiary air flow is measured with the use of long radius ASME flow nozzles designed in accordance with ASME test codes [Ref. 5] and constructed of fiberglass. These nozzles are located so that they penetrate the airtight tertiary air plenum, thereby providing the sole means for metering the tertiary air reaching the eductor. By measuring the temperature of the air entering and the pressure differential across the ASME flow nozzles, the mass flow rate of tertiary air can easily be obtained. Flexibility in measuring the tertiary flow is provided by employing different size flow nozzles: two of 20.32 cm (8 in) throat diameter, three of 10.16 cm (4 in) throat diameter, and two of 5.08 cm (2 in) throat diamter. By using various combinations of these flow nozzles, a wide variety of tertiary cross section flow areas can be obtained.

The interior of the tertiary air plenum is pictured in Figure 13. The stand which holds the mixing stack can be seen mounted inside the plenum. Figure 15 shows the diaphragm air seal at the exit plane of the mixing stack. As can be seen, removalble sections were located in the exit plane

door to allow for adjustments to the mixing stack and instrumentation without removing the diaphragms.

## D. ALIGNMENT

The alignment of the mixing stack with the primary air flow nozzles was accomplished using a level, a 30.78 (12.0 in) rule graduated in 0.25 mm (0.01 in) and 45.72 x 30.48 cm (18.0 x 12.0 in) square. The graduated rule and square were to establish the stand-off distance (D/S) and to center the primary flow nozzles within the entrance area of the mixing stack. The geometric alignment was checked for accuracy using pressure readings at symmetric points on the model. Additional verification was obtained by subsequent symmetric exit velocity profiles measurements. The three axis mounting stand, pictured in Figure 16 allowed alignment adjustments to be performed easily.

## E. INSTRUMENTATION

Pressure taps for measuring gage pressures are located inside the primary air uptakes just prior to the primary nozzles, inside the secondary air plenum, inside the tertiary air plenum, and at various points on the model. A variety of manometers, pictured in Figure 17, were used to indicate the pressure differentials. A schematic representation of the pressure measuring instrumentaion is illustrated in Figures 18 and 19. Monitoring of each of the various pressures was facilitated by the use of a scanivalve and a

multiple valve manifold. The scanivalve was used to select the pressure tap to be read, while the multiple valve manifold allowed selection of the optimum manometer for the pressure being recorded. A vent was included in the multiple valve manifold which provided a means of venting the manometers between pressure readings. When taking readings of the pressure distribution in the mixing stack, it was necessary to manually change the tubing from one end of the manometer to the other in order to get the negative pressure readings. The valve manifold provided a selection of a 15.24 cm (6.0 in) inclined water manometer, a 5.08 cm (2.0 in) inclined water manometer, and a 1.27 cm (0.5 in) inclined oil manometer (specific gravity 0.827). In addition, the following dedicated manometers were used in the system: a 50.80 cm (20 in) single column water manometer connected to the primary air flow just prior to the primary nozzles, a 1.27 cm (50 in) U-tube water manometer with each leg connected to a piezometric ring on either side of the orifice plate in the air inlet duct, and a 2.54 cm (1.0 in) inclined water manometer connected to the upstream piezometric ring.

Primary air temperatures, measured at the orifice outlet and just prior to the primary nozzles, are measured with copper-constantan thermocouples. The thermocouples are in assemblies manufactured by Honeywell under the trade name Megapak. Polyvinyl covered 20 gage copper-constantan extension wire is used to connect the thermocouples to a

Newport Digital Pyrometer, model number 267, which provides a digital display of the measured temperature in degrees Fahrenheit. The Newport Digital Pyrometer failed in use and was replaced by an Omega Digital Thermometer, Model Number 2176A. Secondary/tertiary ambient air temperature is measured with a mercury-glass thermometer and recorded in degrees Fahrenheit.

Velocity profiles at the mixing stack exit plane are obtained by using a pitot tube, pictured in Figure 20. The tube is affixed to a mounting template which allows accurate determination of the major axis, minor axis , minor and diagonal positions and distances. Alignment pins allow changes in velocity traverse directions to be made fast and accurately. The pitot tube is used in conjunction with the 15.24 cm (6 in) inclined water manometer for obtaining the velocity pressure head.

An additional objective of this research was to assemble an automated data acquisition system. The data which was used in this thesis was taken "manually", i.e., pressure and temperature values visually acquired from manometer and thermometer. Each piece of data was then inputed into a computer for reduction. Although equipment limitation prevented full automation, "semi-automatic" data acquisition now exists and is described in Appendix B.

# VI. EXPERIMENTAL METHOD

Evaluation of the eductor model requires the experimental determination of pressure differentials across the ASME long radius flow nozzles, temperature of primary and induced air flows, internal mixing stack pressures, and mixing stack exit velocities. These experimentally determined quantities are then reduced to obtain pumping coefficients, induced air flow rates, pressure distributions within the mixing stack, and mixing stack exit velocity profiles. In addition an indication of flow behavior in the stack was accomplished by flow visualization. The performance characteristics of the eductor model are then evaluated to determine the model's relative effectiveness.

The following discussion addresses the individual performance characteristics of the eductor model and how they were determined.

## A. PUMPING COEFFICIENTS

The secondary pumping coefficient and the tertiary pumping coefficient provide the basis for analysis of the eductor model's pumping performance. Thus, changes in eductor model parameters which affect pumping can be noted by a change in pumping coefficient. The pumping coefficient(s) is desired at the operating point corresponding to that of the shipboard prototype. At this point there is no restriction of

the secondary (or tertiary) air flow. In the model, this is simulated by completely opening the air plenum(s) to the environment. However, at this condition, the secondary (or tertiary) air flow rate cannot be measured. Therefore, the eductor's characteristics are determined, plotted, and then extrapolated to find the operating point, see Figure 21.

The pumping characteristics of the eductor model are established by varying the associated induced air flow rate, either secondary or tertiary, from zero to its maximum measurable rate. This rate is determined by sequentially opening the ASME flow nozzles mounted in the appropriate plenum and recording the pressure drop accross the nozzles. Values for nozzle cross sectional area, pressure drop, and induced air temperature are then used to calculate the dimensionless parameters $P^*/T^*$ and $W^*T^{*0.44}$ or $PT^*/TT^*$ and $WT^*TT^{*0.44}$ as described in Appendix A. The dimensionless parameters are then plotted as illustrated in Figure 21. Extrapolation of the pumping characteristics curve to intersect with the zero pressure/temperature coefficient abscissa locates the appropriate operating point coefficient of the model.

## B. INDUCED AIR FLOWS

Two induced air flows are identified in this study: secondary and tertiary.

The secondary air flow is the amount of air induced by the primary nozzles which mixed with the primary air flow to reduce the exhaust gas temperature.

The tertiary air flow indicates the amount of air induced by the stack pressure distribution to provide cooling air through the ports in the stack plug. In addition to the method of metering tertiary air flow as described in Section III, the effect on the tertiary pumping coefficient by varying the number of rows of cooling ports open, see Figure 6, was investigated.

## C. PRESSURE DISTRIBUTIONS

The mixing stack axial static pressure was obtained using a series of pressure taps fixed to the mixing stack. These taps were placed in two axial rows, the rows being along the centerline of the flow. Along each row the taps were axially spaced in increments of one quarter primary dimension. The exact location of the pressure taps is indicated on Figure 2 and 4. The non-dimensional stack pressure, PMS*, (see Appendix A) is plotted versus X/S to obtain a mixing stack pressure distribution, see Figures 26a through 26l.

## D. EXIT VELOCITY PROFILES

Velocity profiles at the mixing stack exit were calculated from the pressures measured using the pitot tube pictured in Figure 20. Since it was impractical to obtain a complete three-dimensional plot of velocities at the exit plane of

the mixing stack, advantage was taken of the symmetry of the velocity surface resulting from the arrangement of the primary nozzles. Only three traverses were made. The first traverse passes vertically along the centerline down the mixing stack exit, the second traverse passes horizontally across the mixing stack. This traverse, along the centerline, passes across the top of the plug. The third traverse passes diagonally through the intersection of the centerlines. Figure 22 illustrates the orientation and identification of the three velocity traverses, while Figures 27a through i, show plots of the velocity traverses.

## E. FLOW VISUALIZATION

Based upon Shaw's results it was felt necessary to obtain a visual indication of the flow patterns in the mixing stack. Visualization of flow was accomplished by using string or yarn placed in the flow stream. Two procedures were used. The first utilized a string the length of the mixing stack. With this string the shape of the air stream flow throughout the entire mixing stack could be seen. The second procedure involved the insertion of a probe with a small string attached to the end of it into the mixing stack. With this procedure it was very easy to investigate specific location within the stack for flow action, particularly for transition regions from positive to negative pressure. In order to record the flow visualizations it was necessary to

use a 16 mm motion picture camera set for a speed of 60 frames per second.

## VII. DISCUSSION OF EXPERIMENTAL RESULTS

Exhaust eductor systems designed for marine gas turbine applications must substantially cool exhaust gases, present an exterior stack surface temperature which will not give an easily detectable infrared signature, and effectively disburse exhaust gases. In order to quantitively evaluate the overall eductor model performance, four areas of performance were identified: the amount of secondary air flow induced by the primary air flow, referred to here as pumping; the degree of mixing of primary and induced air flow within the mixing stack system, referred to here as mixing; the amount of uptake back pressure impressed upon the turbine exhaust by the eductor system; and the amount of cooling air available to reduce the exterior stack temperature of the eductor system. A qualitative means of assessing flow patterns in the mixing stack was accomplished by flow visualization with string placed in the gas flow regions.

The eductor model and its modified configurations in this study were designed to shield the primary flow nozzles from an overhead view and to provide cooling to those surfaces which are visible from above.

The initial tests performed were for flow visualization. The tests showed the following condition within the mixing stack. First there appeared to be large scale turbulence

within the stack. This was demonstrated by the wide range of travel of a string running the length of the stack. Secondly, there was evidence of some sort of reverse flow, probably a vortex formation on the downstream sides of the plug. Finally, there was a demonstration of flow oscillatory interaction at the outlet end of the plug. The range of motions of the strings in the flow is shown in Figure 23.

Further model testing was conducted using an eductor model with the addition of a cusp on the inlet end of the symmetric plug. The tests were conducted with a primary flow nozzle area to mixing stack area ratio of 3.0, a mixing stack length L/S of 3.0 and a standoff distance D/S of 0.5. These ratios of mixing stack length, standoff distance and primary nozzle to mixing stack area were used as a result of the previous study by Shaw [Ref. 8]. The reults of this first set of eductor system tests are shown in Tables I through XIII.

These tests showed the following results. First, the uptake back pressure, over the variation in secondary and tertiary flows tested, showed a reduction of up to .5 inches of $H_2O$. However, at the operating point of the eductor system (secondary and tertiary areas wide open) the back pressure was the same as Shaw's 9.85 inches of $H_2O$. This uptake back pressure may be too high and would impact on the turbine efficiency. Secondly, the eductor model pumping coefficient was improved by approximately sixteen percent

over that of Shaw. Figure 24a demonstrates that with Shaw's design the pumping coefficient at the operating point would be less than 0.3. With the addition of the cusp alone, the pumping coefficient is increased above 0.35. Finally, the velocity profiles in all three direction; vertical, horizontal, and diagonal showed little change from Shaw's data. On the average these profiles were relatively flat. These velocity traverses are depicted in Figures 17a through 27i.

The next mixing stack modification was the replacement of a sharp corner in the sides with a curved section that smoothly transitioned from the ducting over the plug to the exit ducting. The results of the tests performed after this modification are tabulated in Tables XIII through XVIII.

Initial comparisons of data were with the back pressures obtained. Over the ranges of secondary and tertiary flow combinations the back pressures increased over those values recorded for the cusp only addition. However, at the wide open operating point the back pressure was the same as that with the cusp only and with Shaw's data, 9.85 inches of $H_2O$. With the addition of the side modification the pumping coefficient, over the range of flows used, was reduced from those values obtained without the side modification (see Figure 24c). The pumping coefficients at the operating point without and with the side modification were essentially the same. Finally, the velocity profiles in all three directions showed more variation with the side modification

than previously. However, in the aggragate these profiles were still relatively flat. These traverses are in Figures 27g, h and i.

The following observations were made in comparing the cooling (tertiary) pumping coefficients ($WT^*TT^{*0.44}$). Concomitant with an increase or decrease in secondary pumping coefficient was an inverse action with the tertiary pumping coefficient. The addition of the cusp decreased the tertiary pumping coefficient from .060, the value obtained by Shaw, by approximately 33% to .040 (see Figure 25c). Over the ranges of flow combinations tested the addition of the side modification improved the tertiary pumping coefficient. At the operating point the values of the tertiary pumping coefficients for with and without the side modification essentailly converged. These results are displayed in Fifures 25a through 25g.

It was further noted that decreasing the number of tertiary ports open had the effect of increasing the secondary pumping coefficient and consequently decreasing the tertiary pumping coefficient.

The final indicator looked at was the pressure distribution in the mixing stack. The data obtained was essentially unchanged from that of Shaw's. Positive pressures occurred along the exterior curved surface of the mixing stack. As with Shaw, a large negative pressure (PMS*) = - 0.30, occurs at the junction of the curved surface and

the rectangular mixing stack exit plane. It was noted that with the addition of the cusp only, this large negative pressure (PMS*) increased to a value of -0.35 (Figure 26a). With the further modification of the curved side the large negative pressure was significantly reduced to -.15, a value much less than Shaw's (Figure 26i). No significant pressures were noted along the flat surface of the mixing stack.

# VI. CONCLUSIONS

This investigation studied the effects on the eductor system's overall performance of a mixing stack geometry which has a rectangular cross-section and employs a plug placed over the primary flow nozzles. The plug was modified with the addition of a cusp on the inlet end. The sides of the mixing stack was further modified to remove a sharp corner.

The conclusions resulting from this investigation are given here.

1. The addition of the cusp on the plug increased the secondary pumping coefficient and increased a negative pressure at a point within the mixing stack.
2. The addition of the cusp reduced the tertiary cooling pumping coefficient.
3. The modification of the sides of the mixing stack reduced the negative pressure at the specific point within the mixing stack.
4. The modification to the curved side of the mixing stack did not improve the performance of the eductor system and should be removed.

# VII. RECOMMENDATIONS FOR FURTHER STUDY

This study showed the effects on a specific eductor system with several geometric configurations. This research adds some information to the overall data base upon which further research can be conducted. Recommendations for further investigation of this eductor system are presented here.

1. Further explore the flow patterns within the stack using tufting or some other flow visualization process.
2. Test the eductor model with the following modifications: remove the side modification, add an exterior shroud to the mixing stack and add a diffusor configuration to the exit plane of the mixing stack.

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2. Moss, C.M., Effects of Several Geometric Parameters on the Performance of A Multiple Nozzle Eductor System, Master's Thesis, Naval Postgraduate School, September 1977.

3. Harrell, J.P. Jr., Experimentally Determined Effects of Eductor Geometry on the Performance of Exhaust Gas Eductors for Gas Turbine Powered Ships, Engineer's Thesis, Naval Postgraduate School, September 1977.

4. Pucci, P.F., Simple Eductor Design Parameters, Ph.D. Thesis, Stanford University, September 1954.

5. American Society of Mechanical Engineers Interim Supplement 19.5 on Instrumentation and Apparatus, Fluid Meters, Sixth edition, 1971.

6. Kline, S.J. and McClintock, F.A., "Describing Uncertainties in Single-Sample Experiments," Mechanical Engineering, p. 3-8, January 1953.

7. Lemke, R.J. and Staehli, C.P., Performance of Multiple Nozzle Eductor Systems with Several Geometric Configurations, Master's Thesis, Naval Postgraduate School, September 1978.

8. Shaw, R.S., Performance of a Multiple Nozzle Exhaust Gas Eductor System for Gas Turbine Powered Ships, Master's Thesis, Naval Postgraduate School, December 1980.

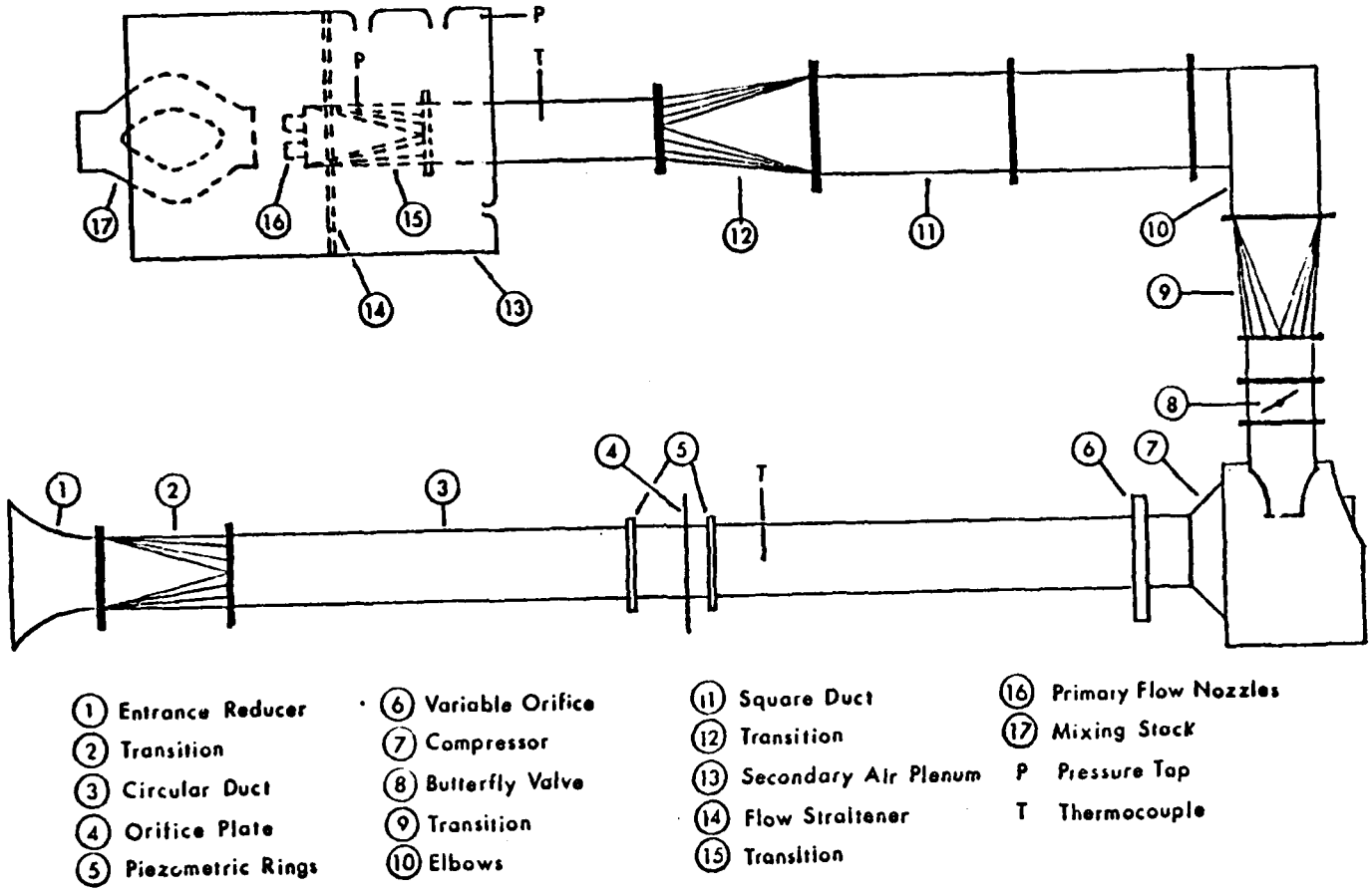



FIGURE 1. EDUCTOR MODEL TESTING FACILITY

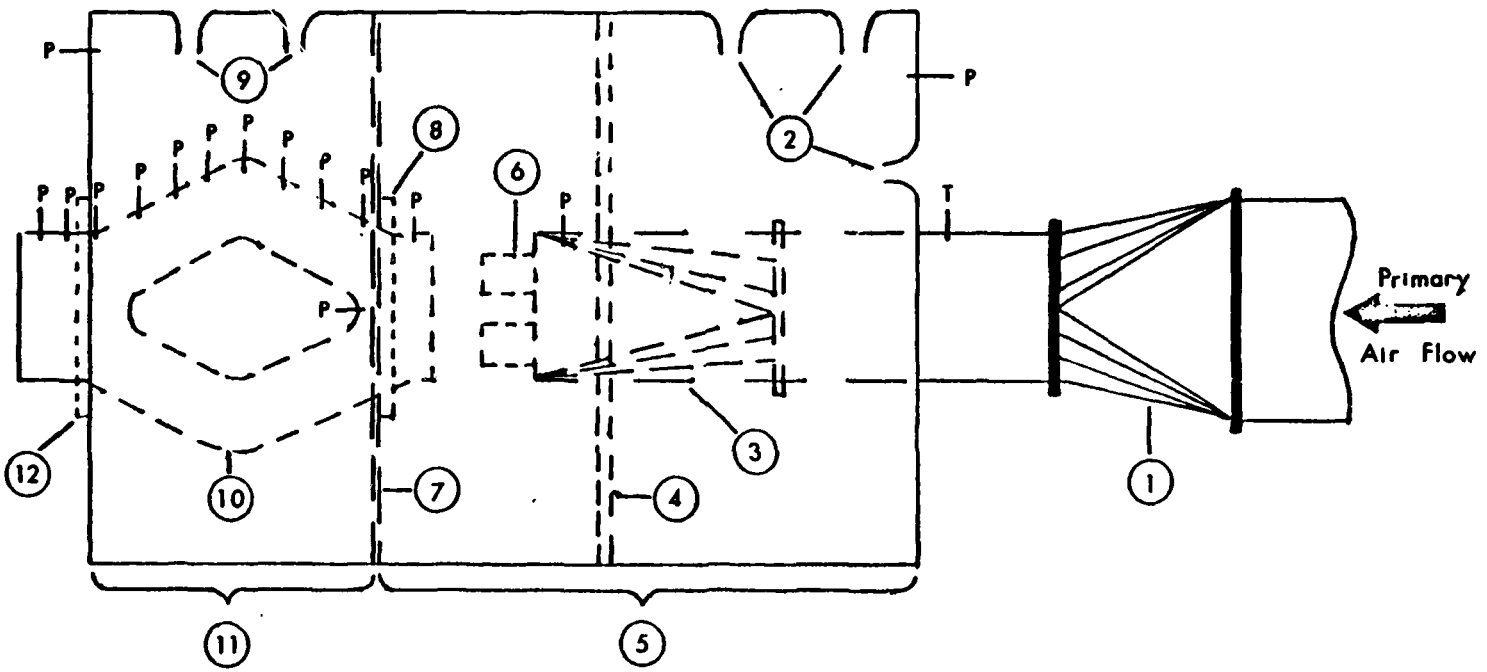



FIGURE 2. EDUCTOR MODEL WITH SECONDARY AND TERTIARY PLENUMS

S - Mixing Stack Primary Dimension

L - Mixing Stack Length

D - Stand Off Distance

I - Nozzle Length

P Symmetric Plug Length

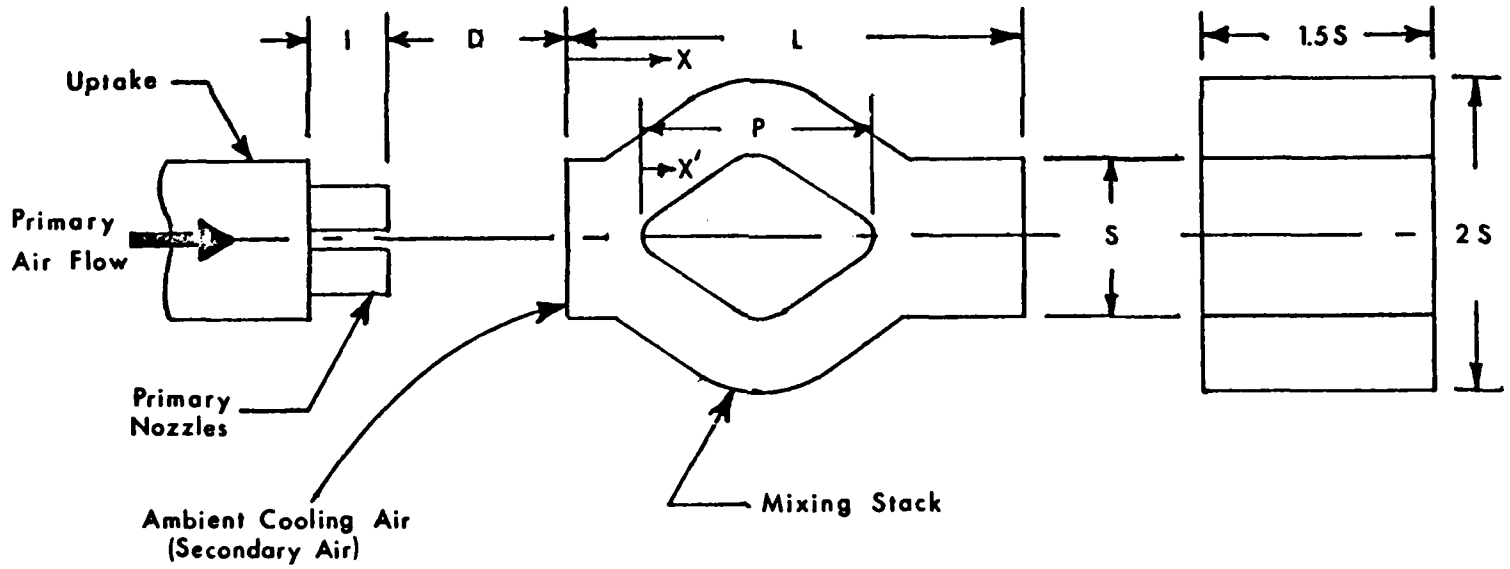



FIGURE 3. SCHEMATIC OF MIXING STACK EDUCTOR

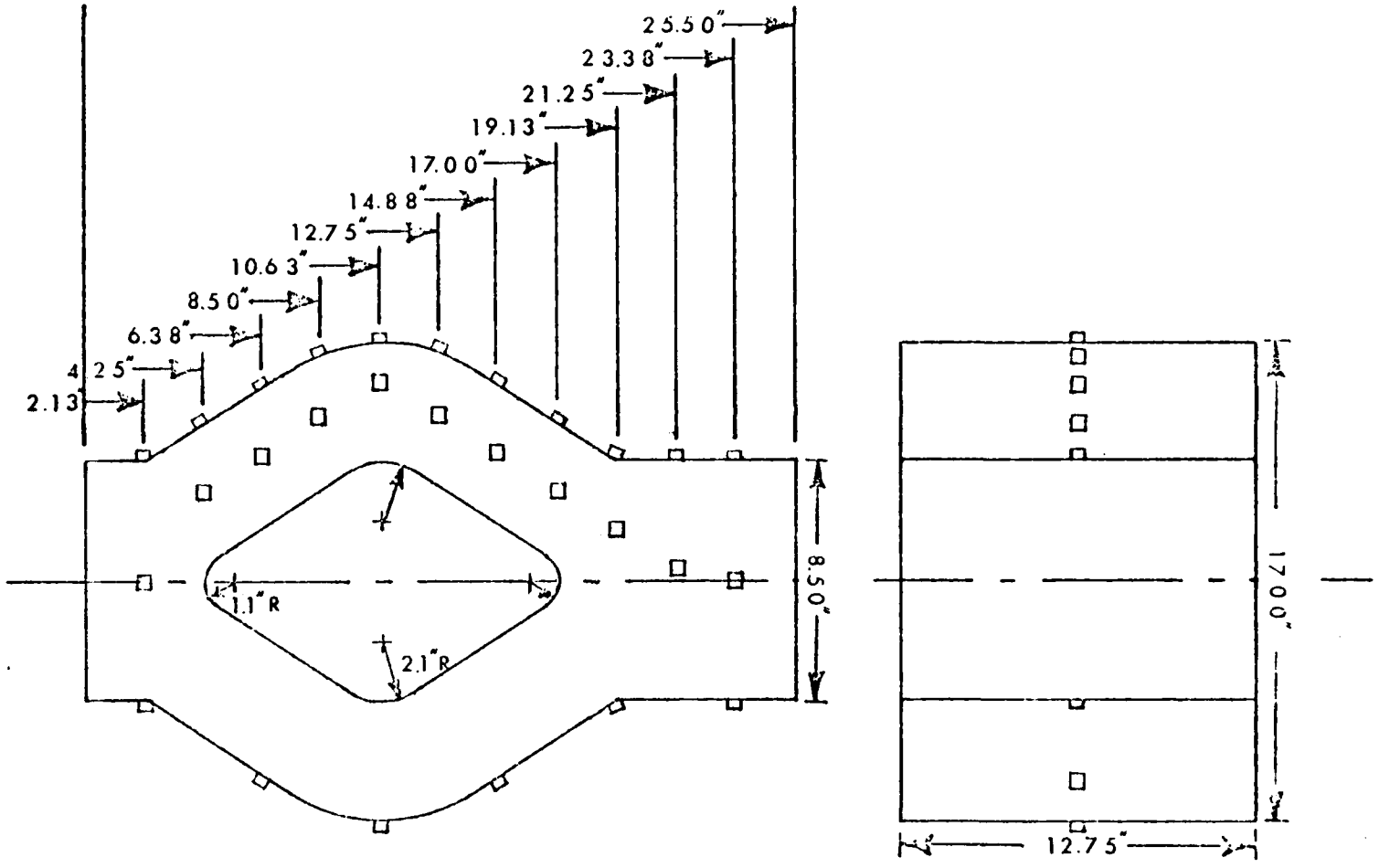



FIGURE 4. MIXING STACK WITH SYMMETRIC PLUG

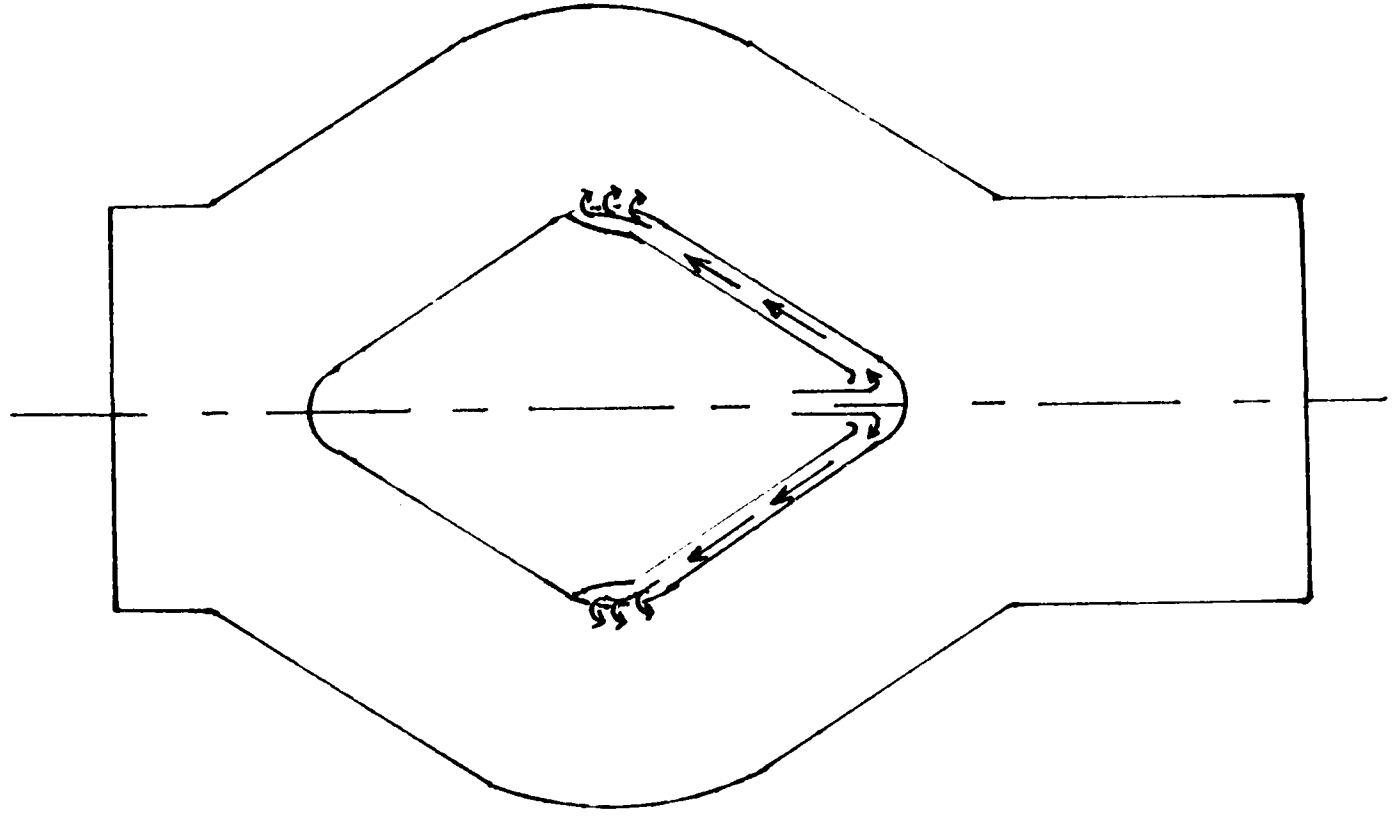


FIGURE 5. MIXING STACK WITH PORTED AND SHROUDED PLUG

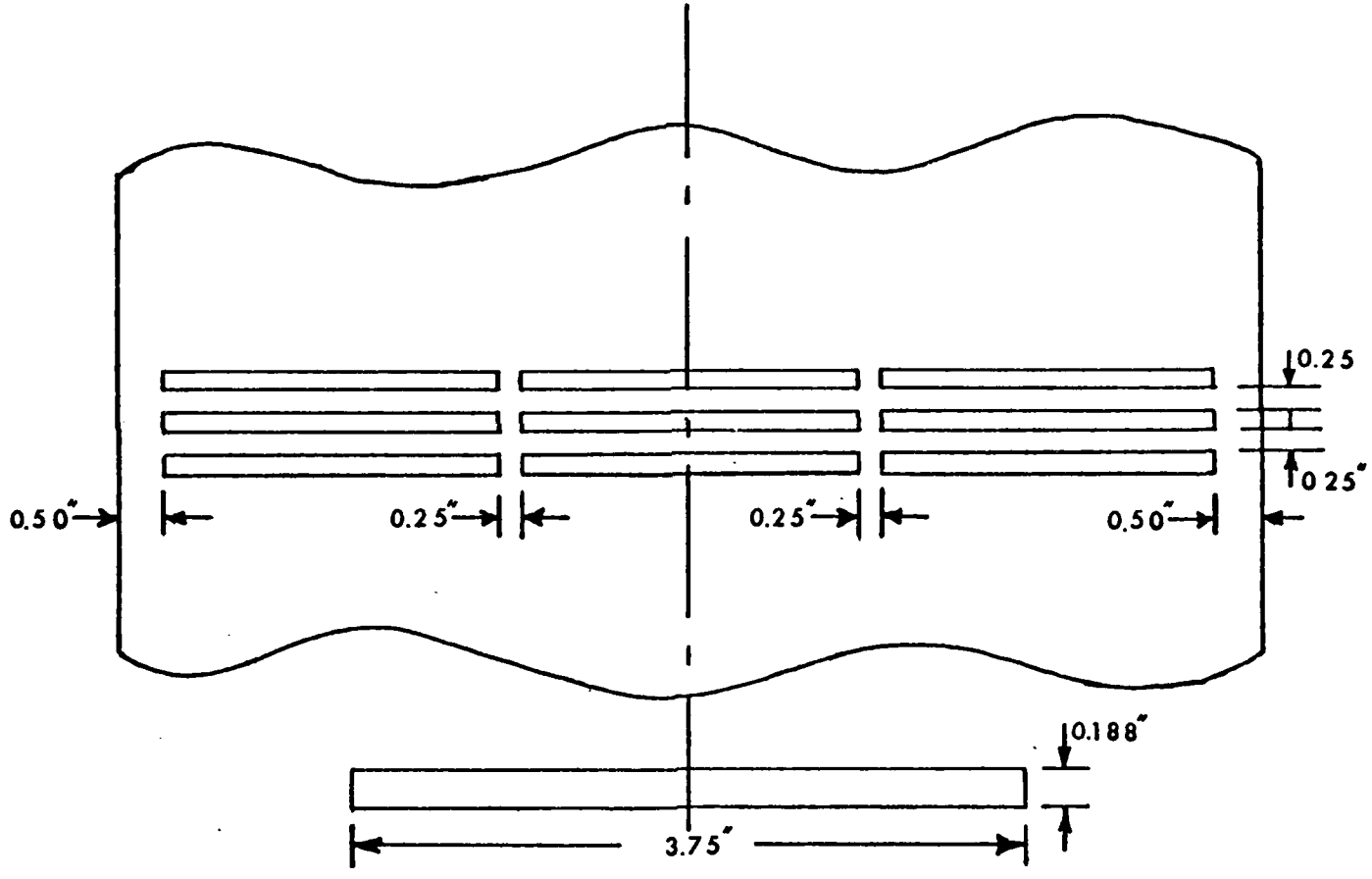



FIGURE 6. SCHEMATIC OF PLUG PORTING ARRANGEMENT

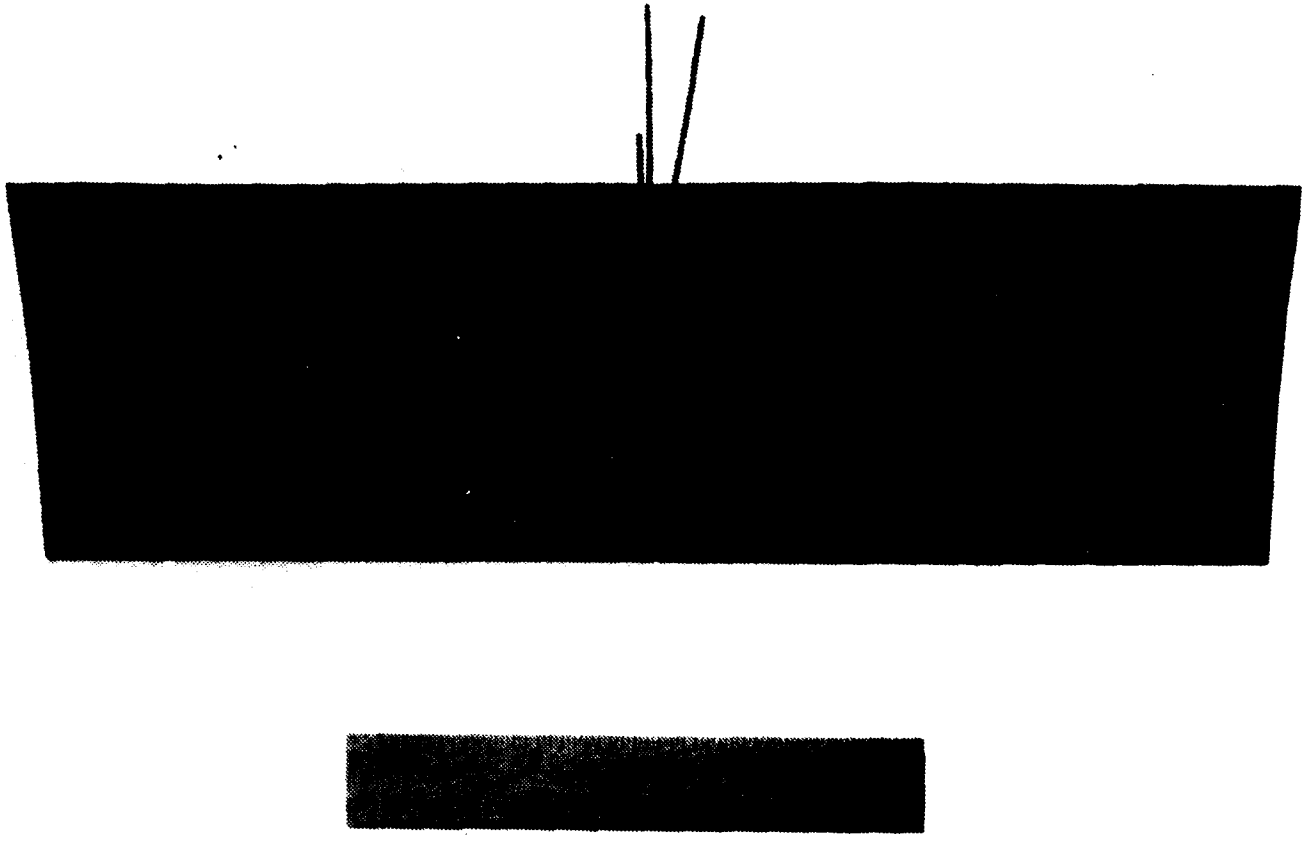


FIGURE 7. CUSP ILLUSTRATION

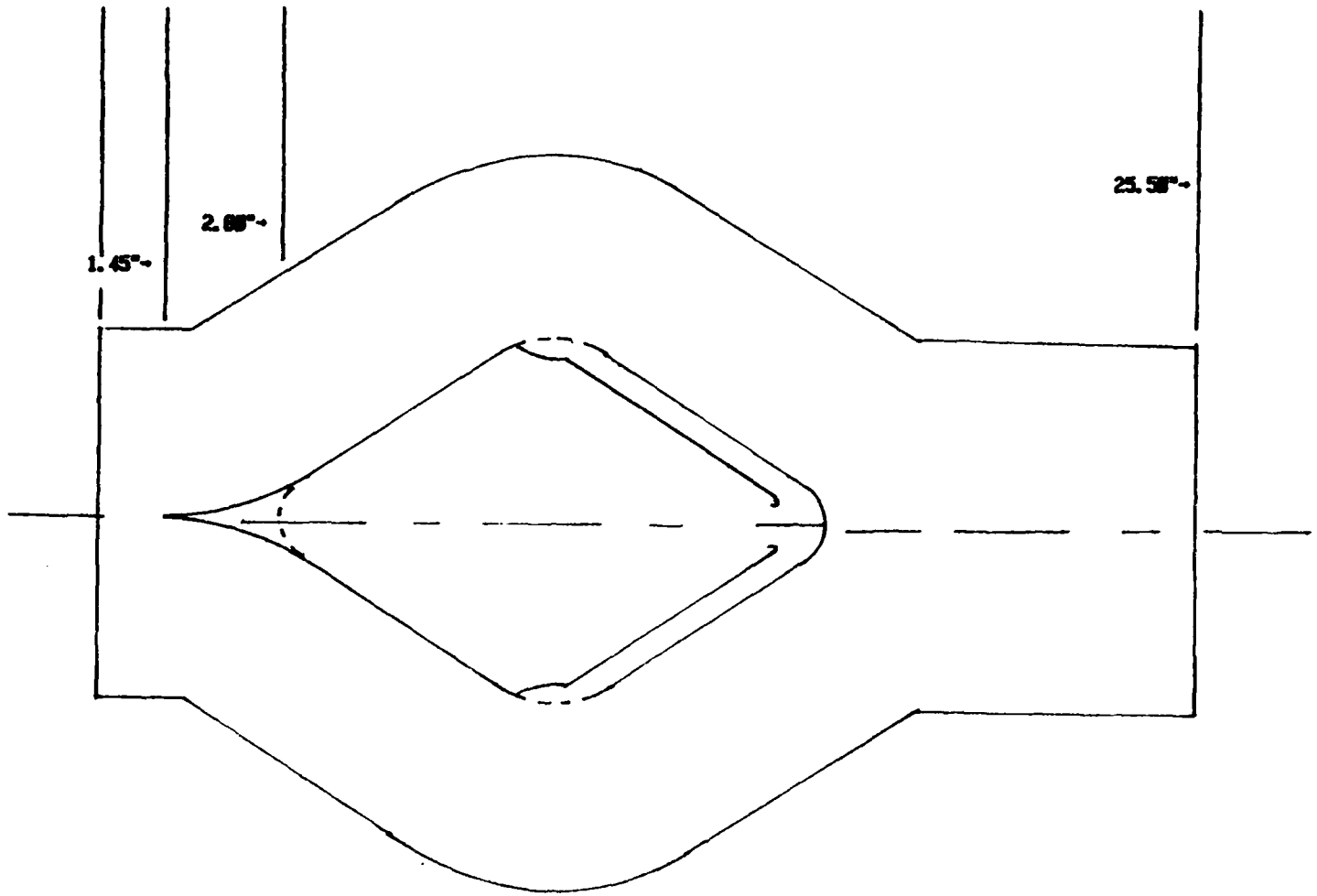



FIGURE 8. DIMENSIONAL ILLUSTRATION OF MIXING STACK WITH CUSP

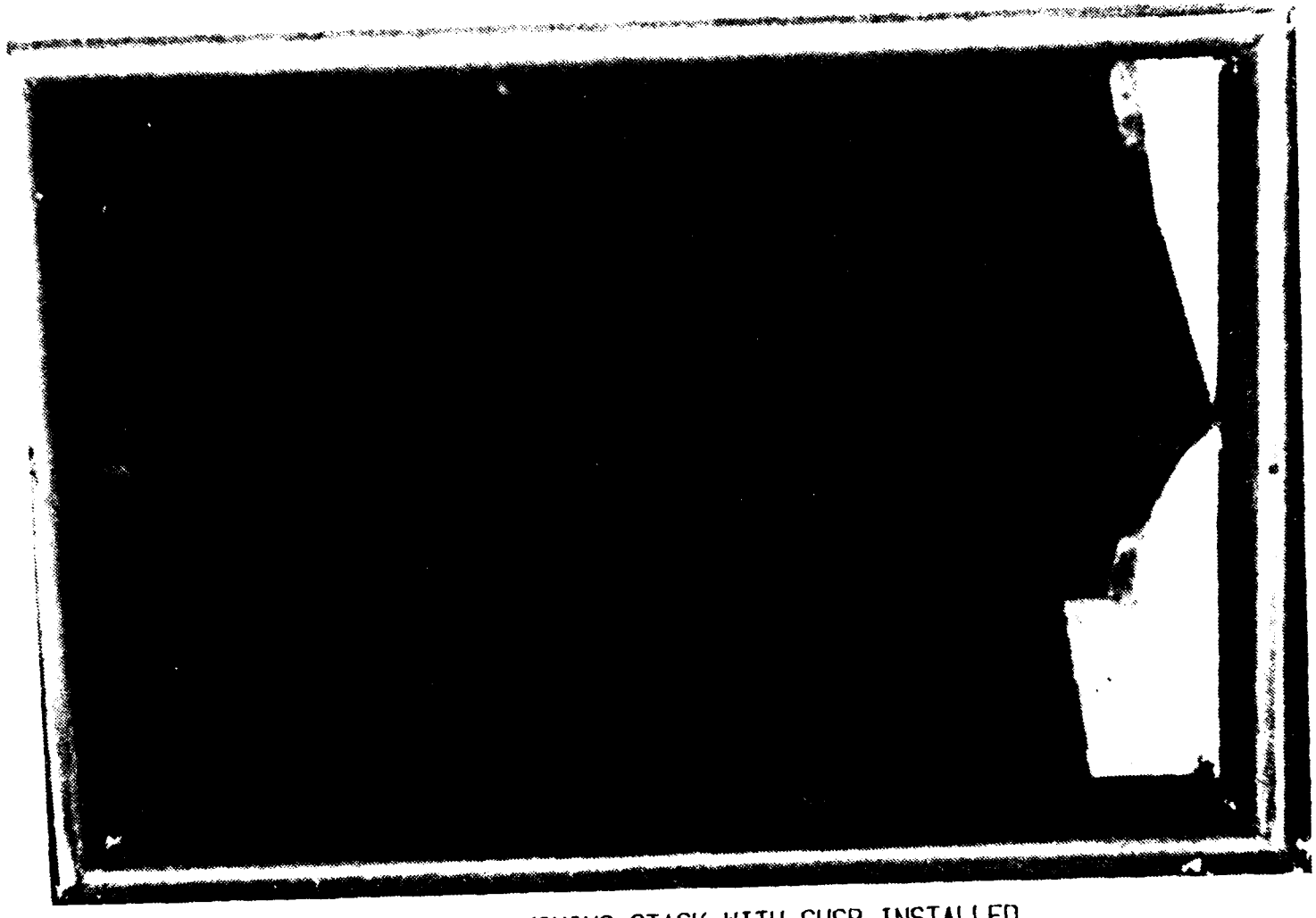


FIGURE 9. MIXING STACK WITH CUSP INSTALLED

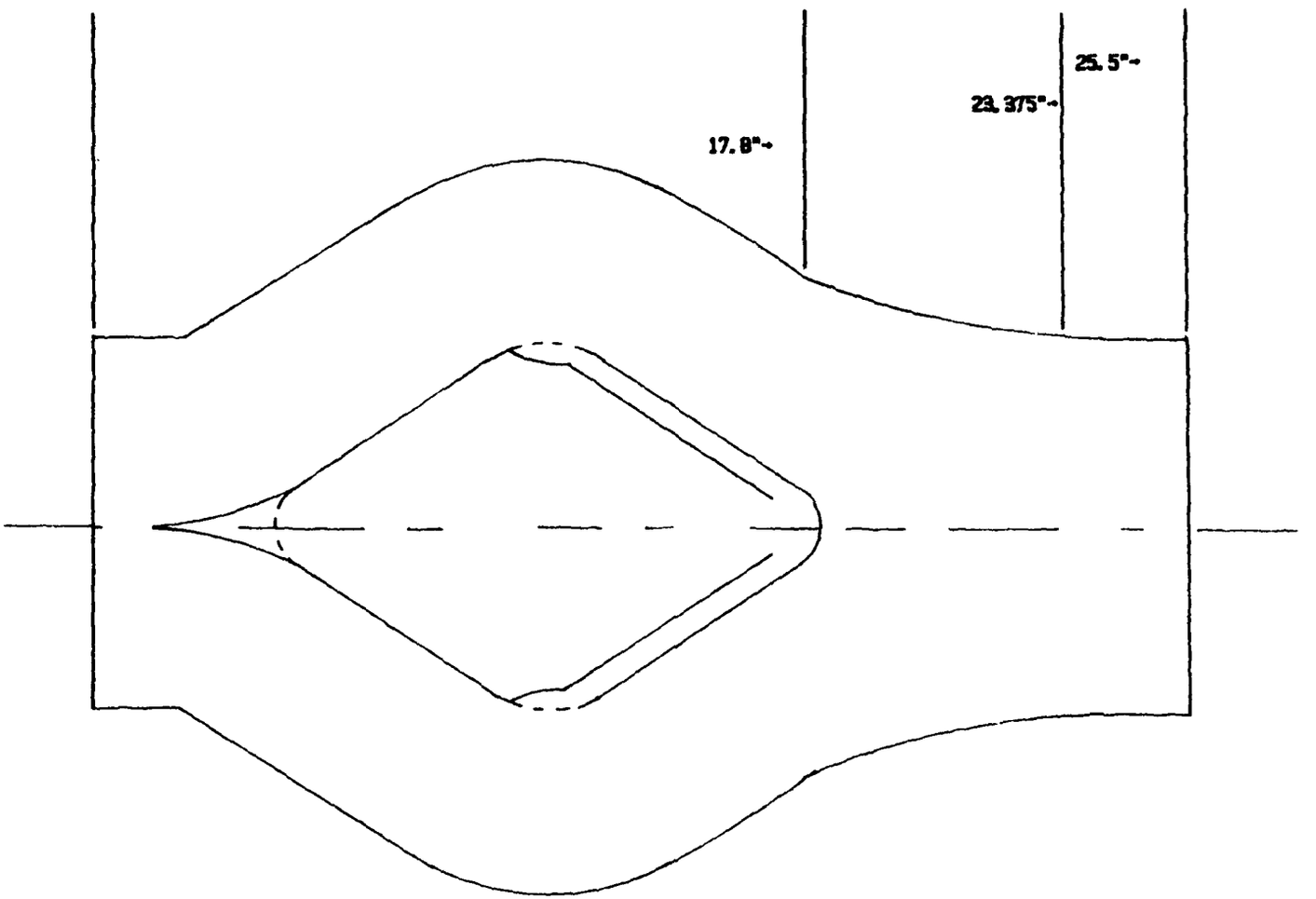



FIGURE 10. DIMENSIONAL ILLUSTRATION OF MIXING STACK WITH CUSP AND SIDE MODIFICATION

FIGURE 11. MIXING STACK WITH CUSP AND SIDE MODIFICATION

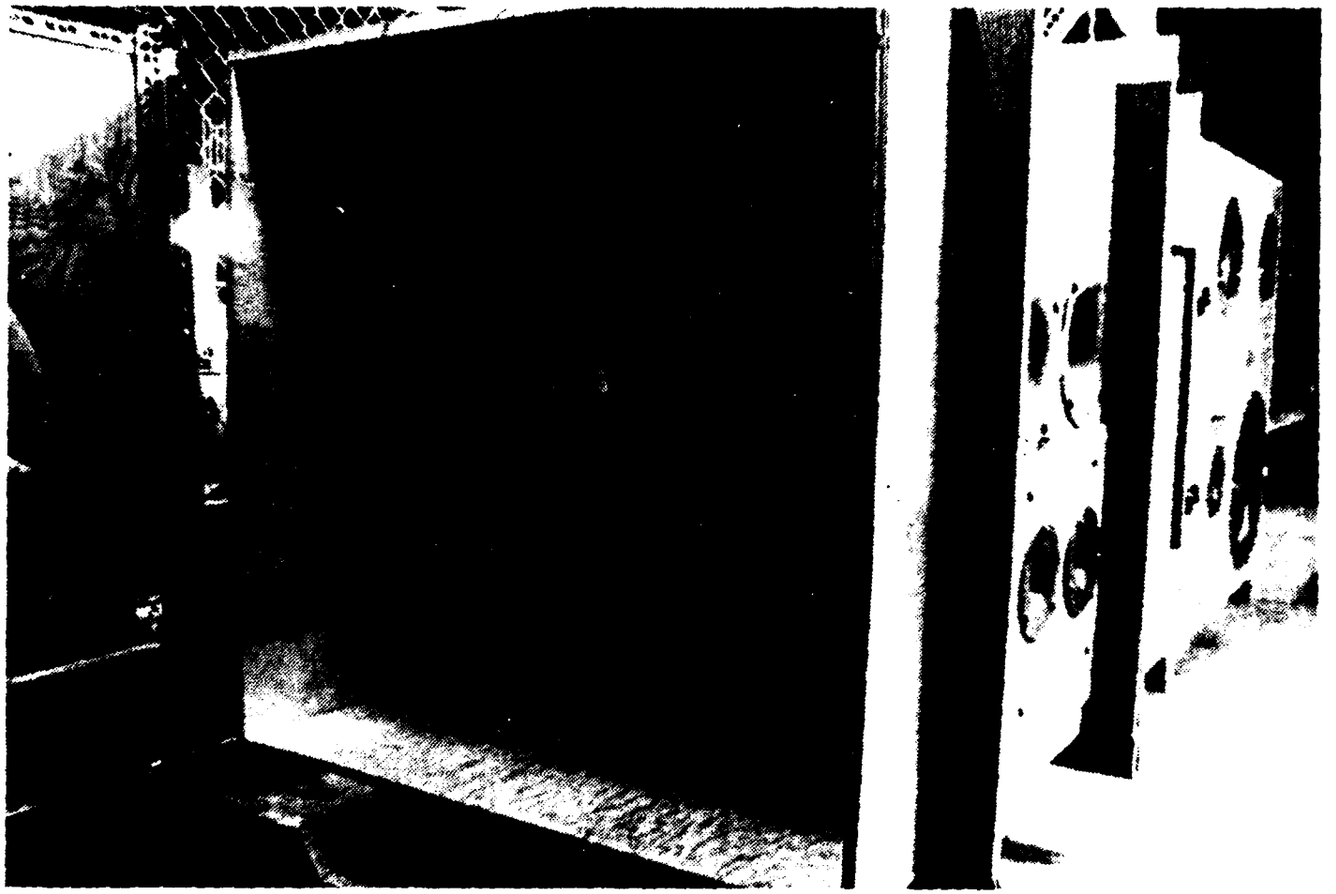


FIGURE 12. SECONDARY AND TERTIARY AIR PLENUMS

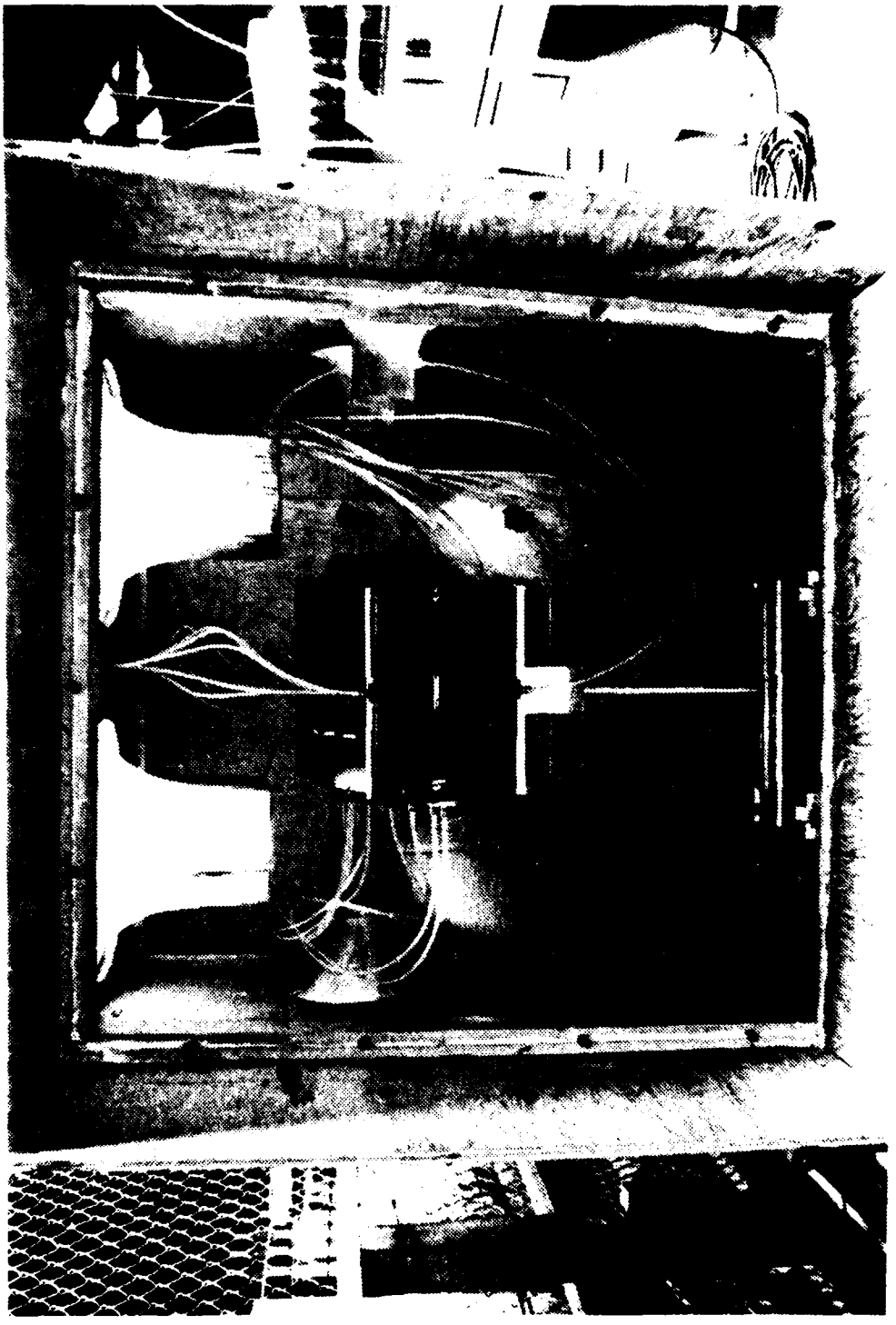


FIGURE 13. TERTIARY AIR PLENUM INTERIOR

FIGURE 14. MIXING STACK ENTRANCE WITH AIR SEAL

FIGURE 15. MIXING STACK EXIT WITH AIR SEAL

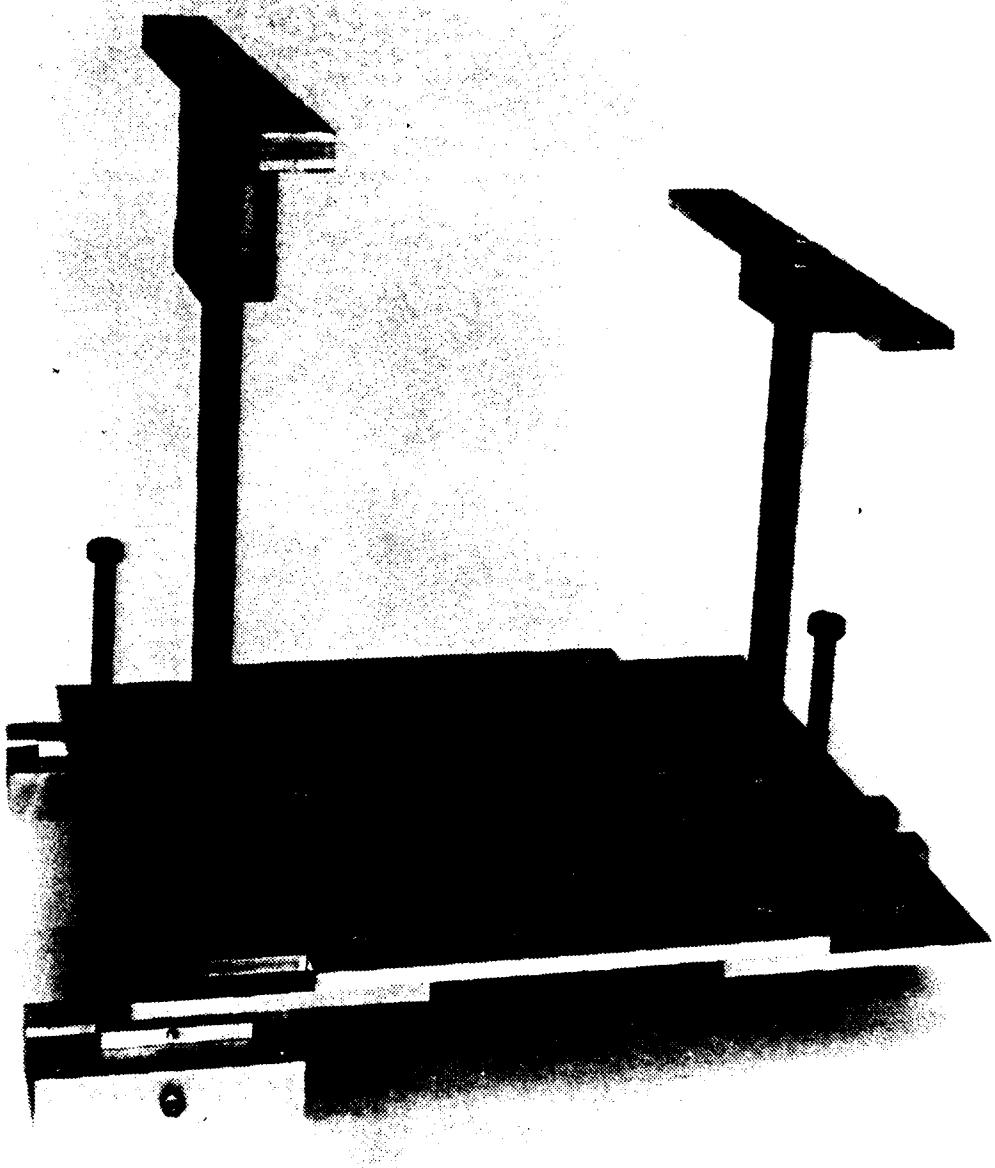


FIGURE 16. MIXING STACK MOUNTING STAND

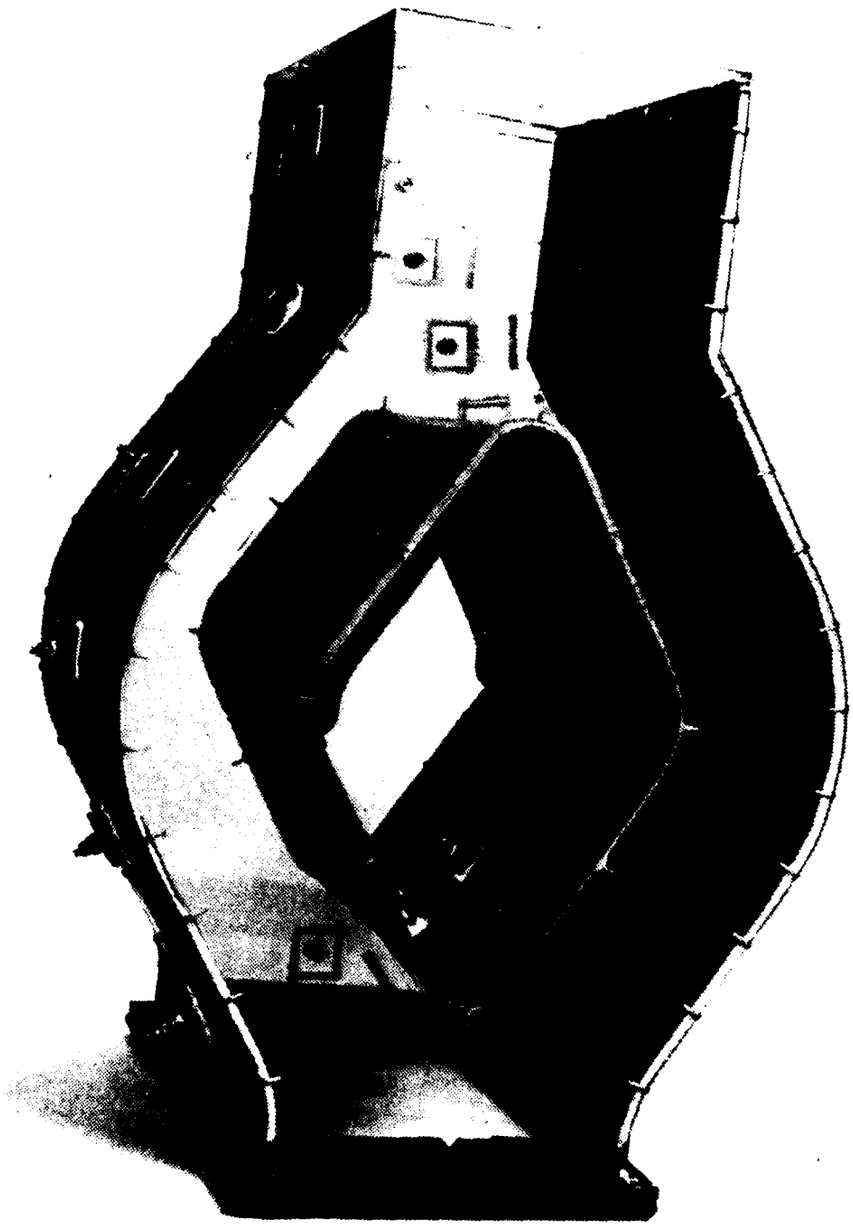
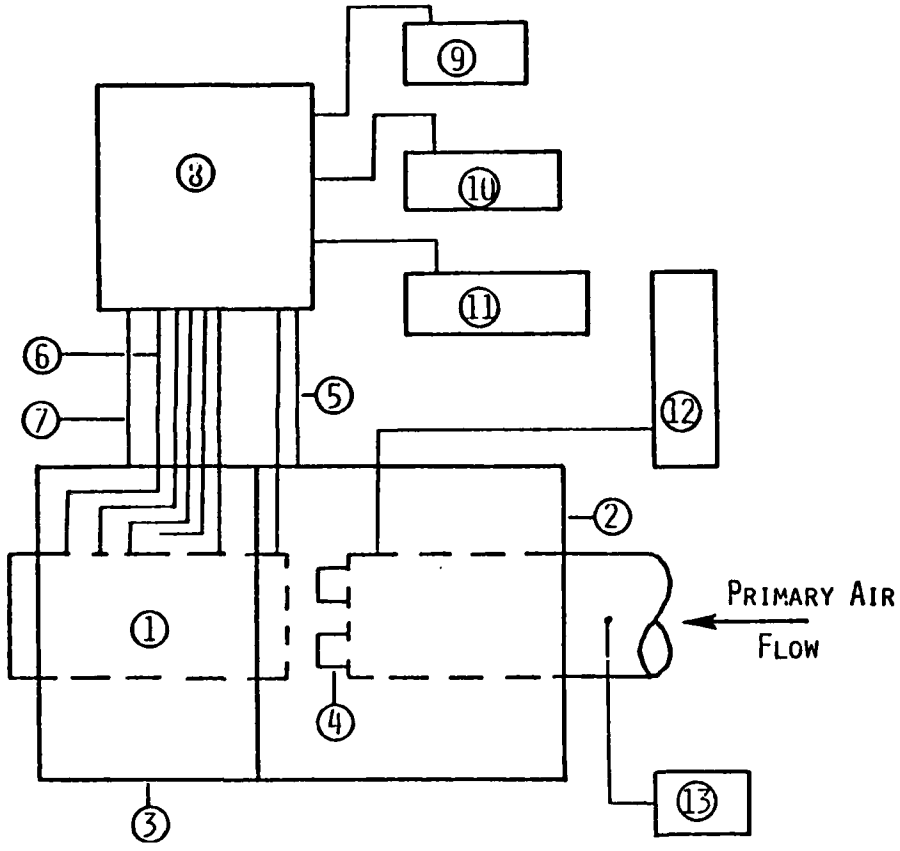


FIGURE 17. MIXING STACK WITH PORTED AND SHROUDED PLUG




① MIXING STACK
② SECONDARY AIR PLENUM
③ TERTIARY AIR PLENUM
④ PRIMARY FLOW NOZZLES
⑤ PRESSURE DIFFERENTIAL ACROSS SECONDARY AIR PLENUM
⑥ PRESSURE SENSING LINES FOR MIXING STACK
⑦ PRESSURE DIFFERENTIAL ACROSS TERTIARY AIR PLENUM
⑧ SCANIVALVE
⑨ 0.5" MANOMETER
⑩ 2.0" MANOMETER
⑪ 6.0" MANOMETER
⑫ 17.0" MANOMETER
⑬ THERMOCOUPLE READER

FIGURE 18. SCHEMATIC OF INSTRUMENTATION

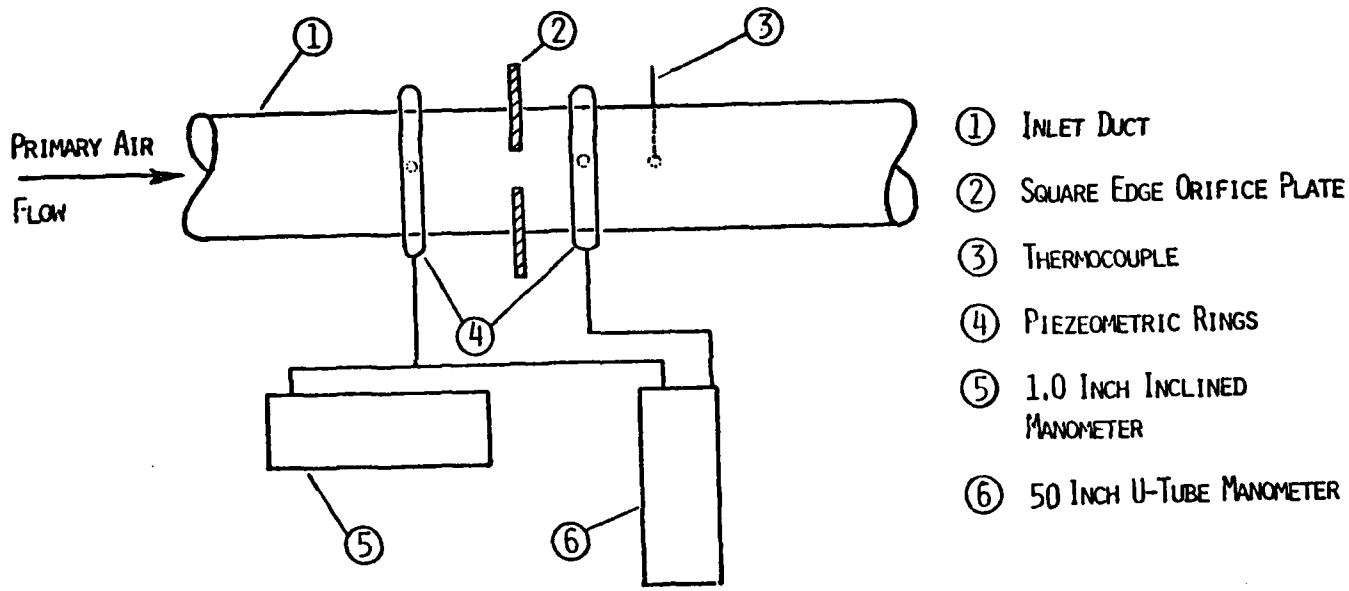



FIGURE 19. SCHEMATIC OF INSTRUMENTATION FOR PRIMARY AIR FLOW MEASUREMENT

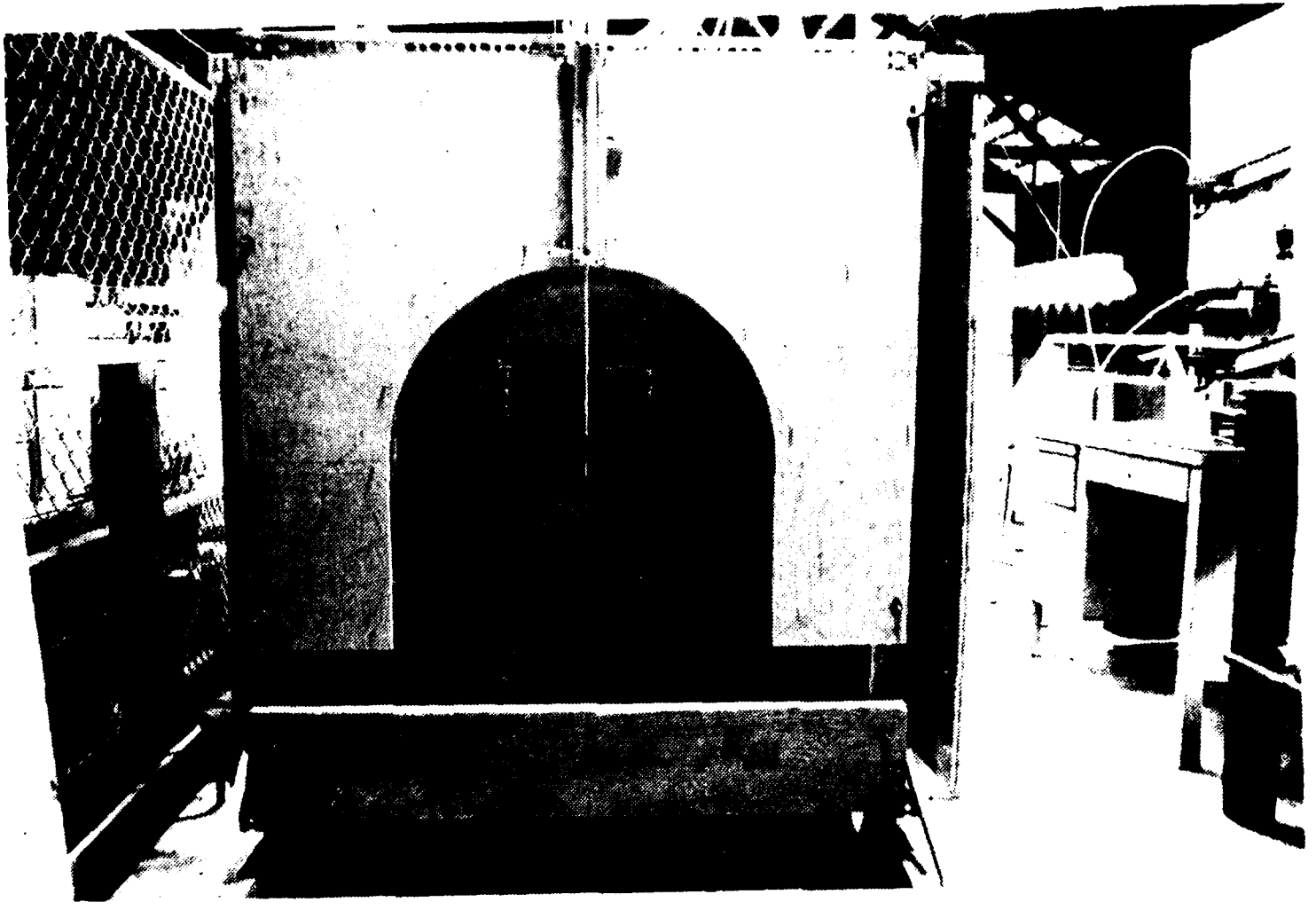


FIGURE 20. VELOCITY PROFILE APPARATUS

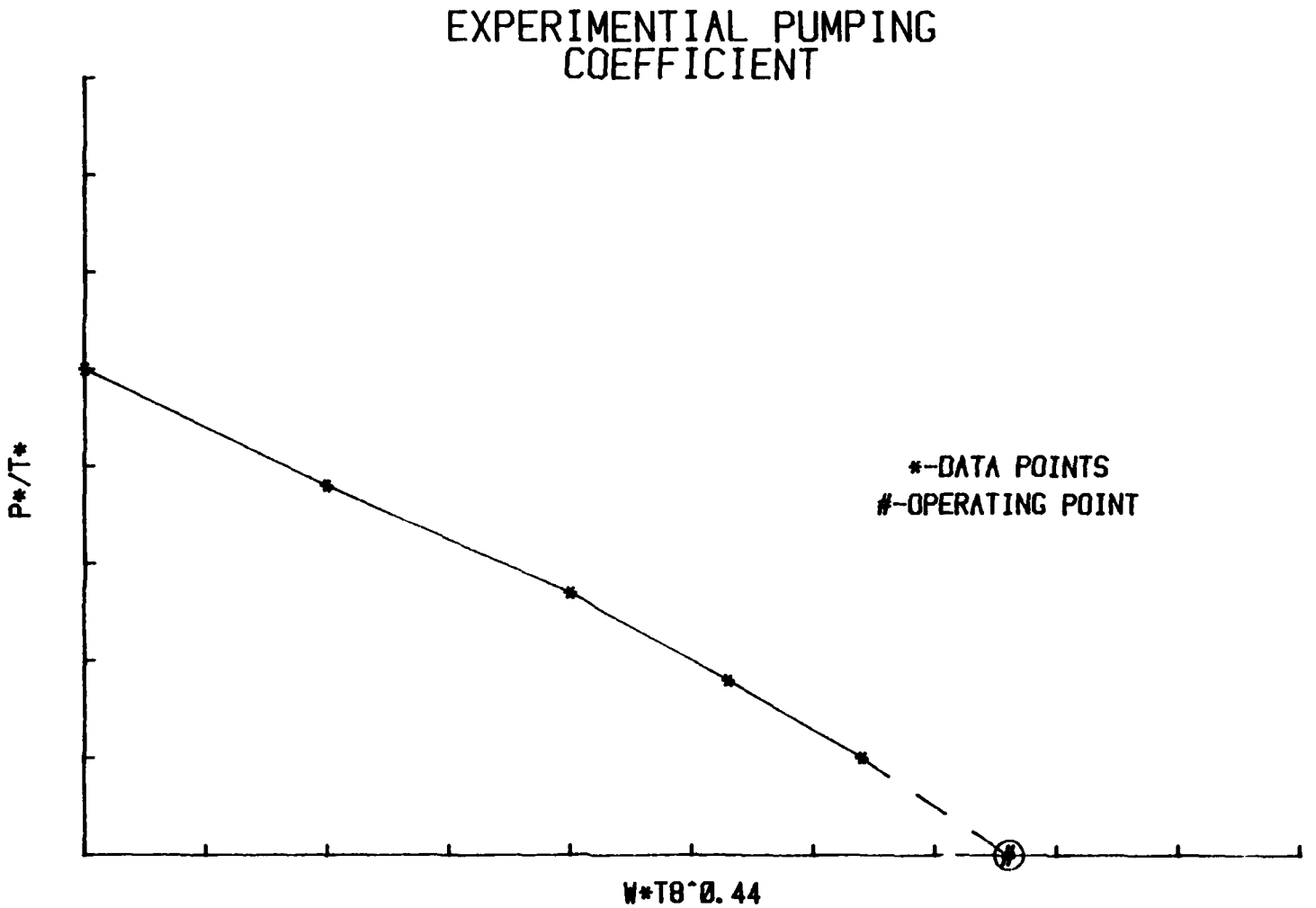



FIGURE 21. EXAMPLE PLOT OF PUMPING COEFFICIENT

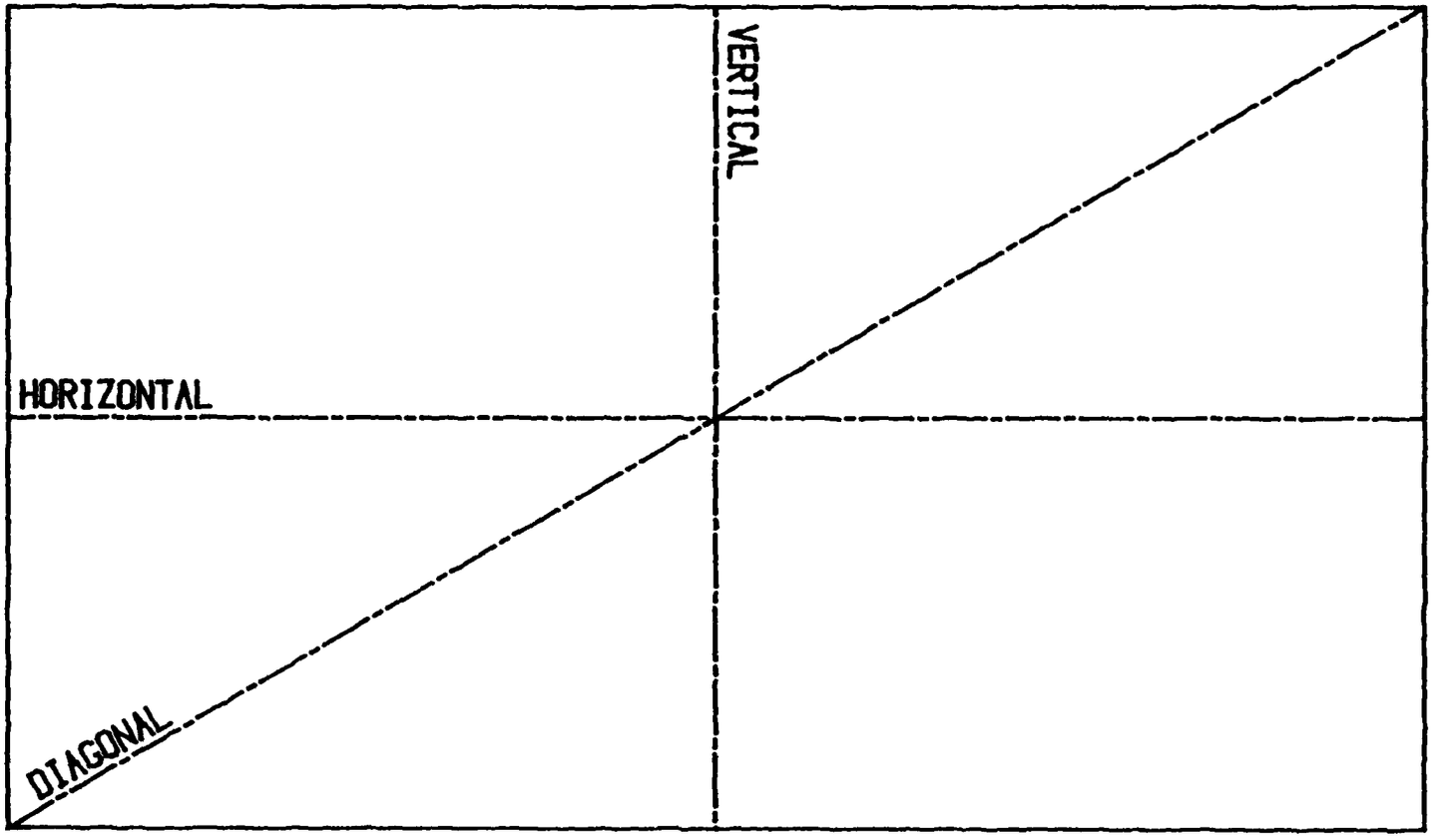



FIGURE 22. VELOCITY TRAVERSE DIRECTIONS

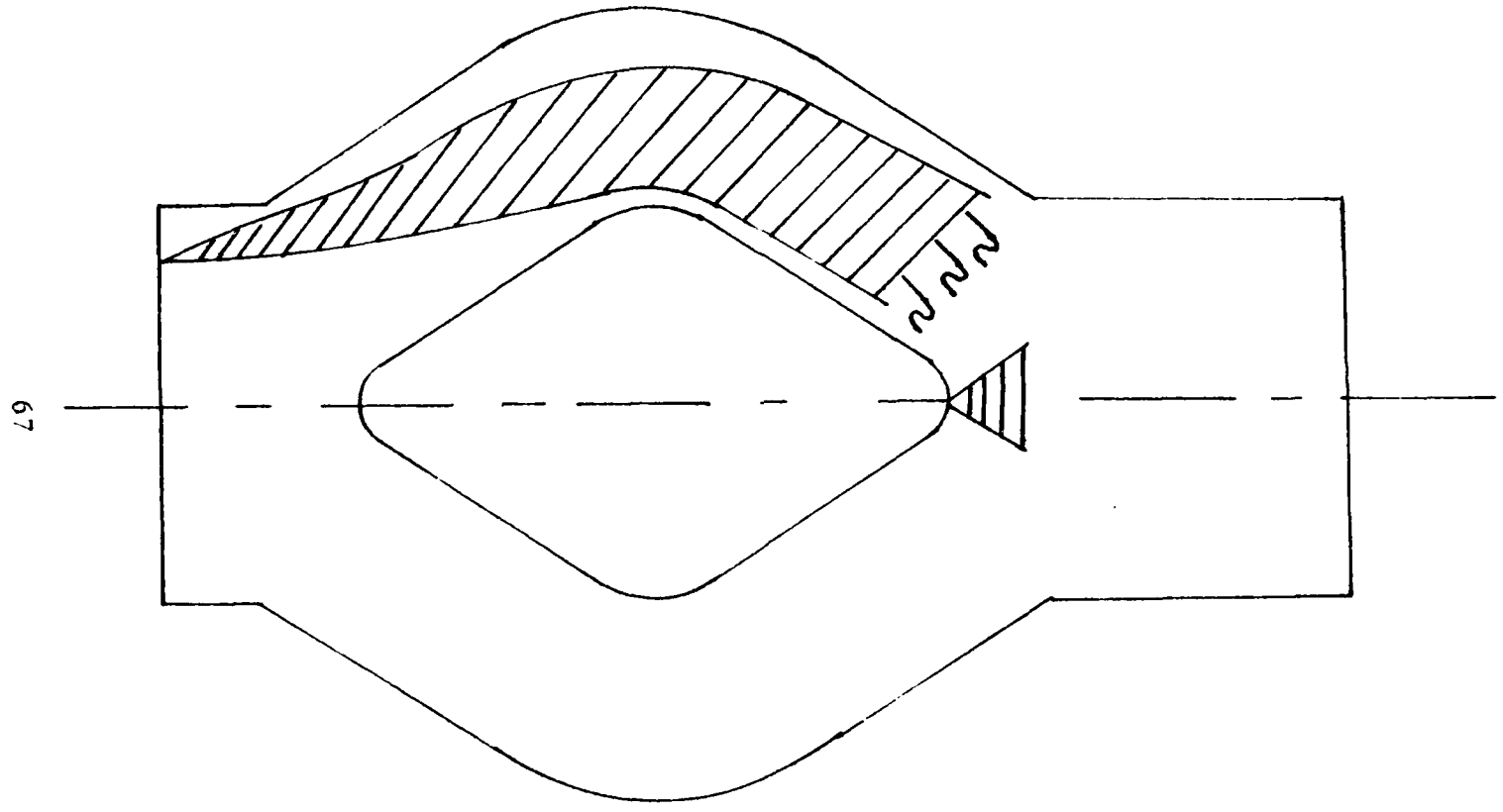


FIGURE 23. SCHEMATIC OF FLOW VISUALIZATION RESULTS

# EXPERIMENTAL PUMPING COEFFICIENT COMPARISON

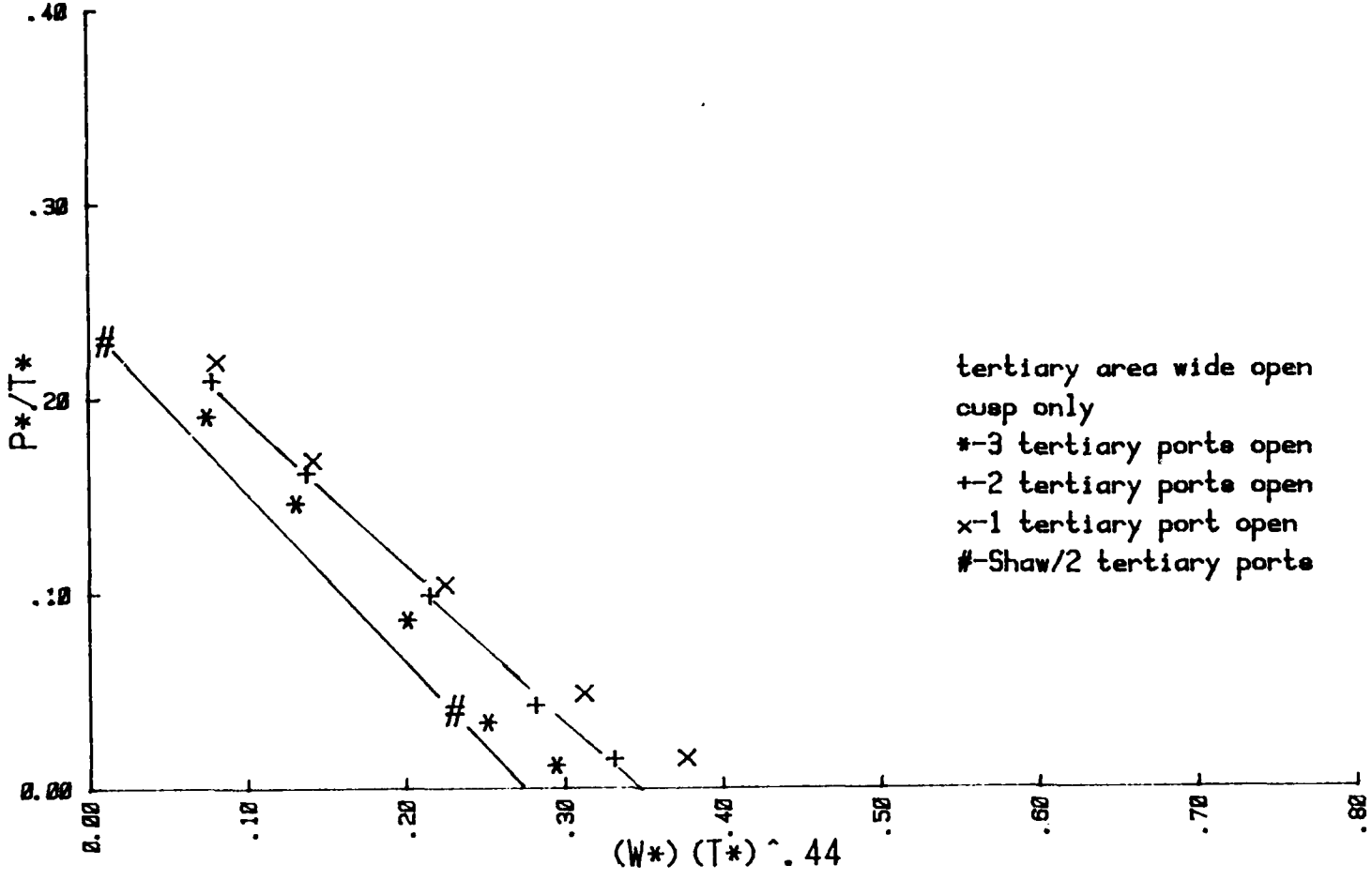



FIGURE 24a

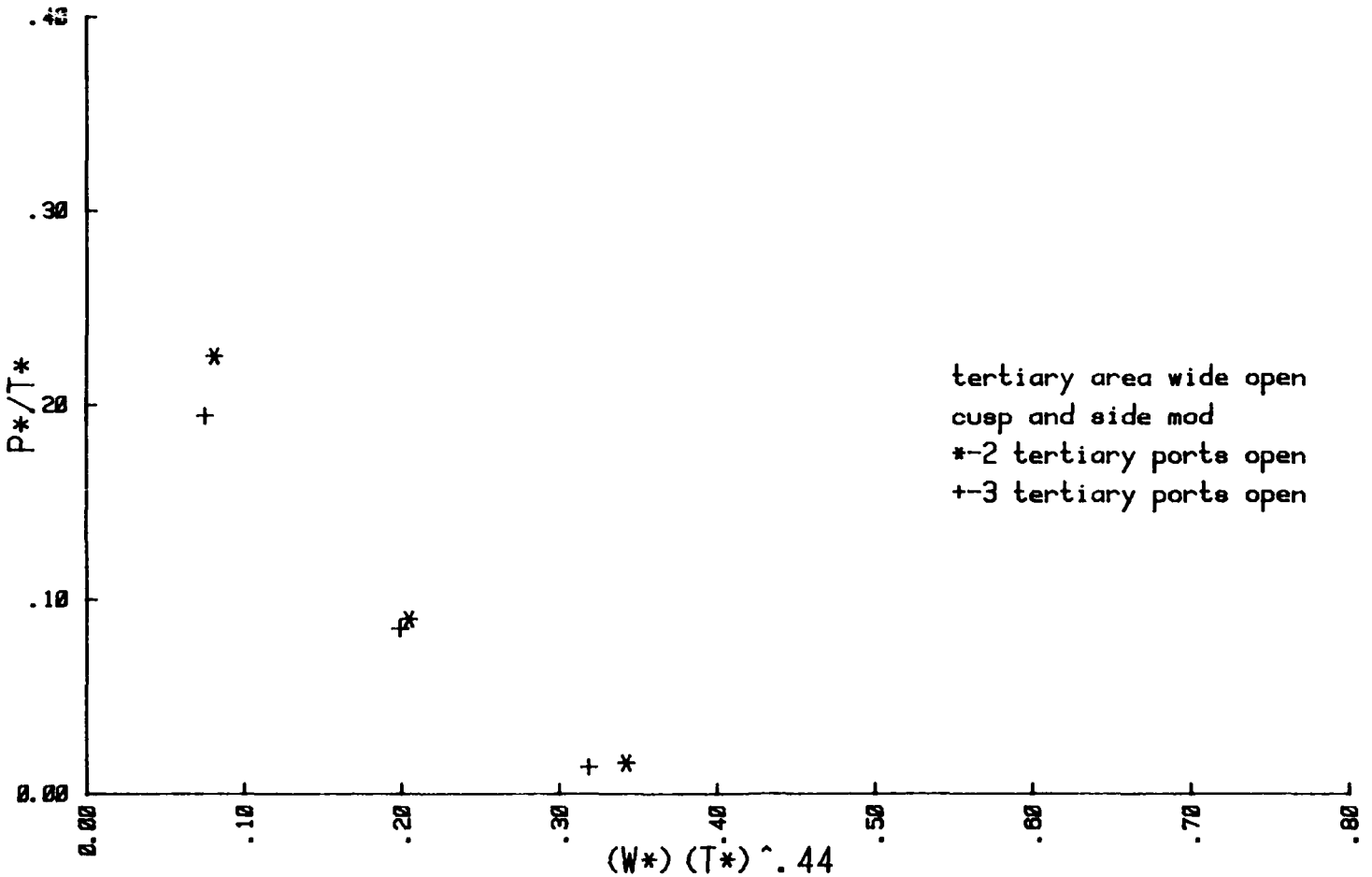

EXPERIMENTAL PUMPING
COEFFICIENT COMPARISON
P*/T*
.30
.20
.10
0.00
0.00
.10
.20
.30
.40
.50
.60
.70
.80
(W*) (T*) ^ .44
tertiary area wide open
cusp and side mod
*-2 tertiary ports open
+-3 tertiary ports open

FIGURE 24b

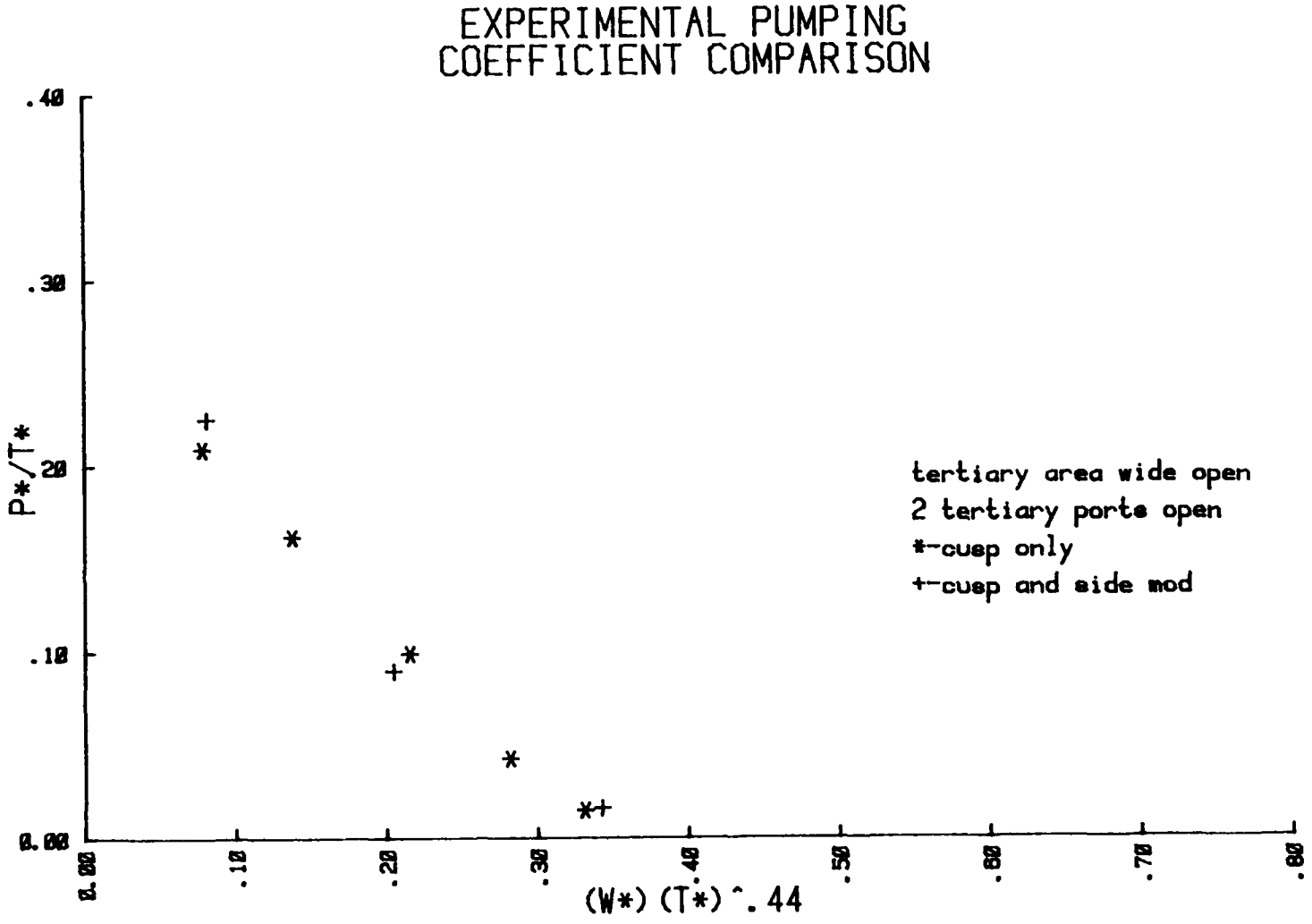

EXPERIMENTAL PUMPING
COEFFICIENT COMPARISON
.40
.30
.20
.10
0.00
P*/T*
0.00
.10
.20
.30
.40
.50
.60
.70
.80
(W*) (T*) ^ .44
tertiary area wide open
2 tertiary ports open
*-cusp only
+-cusp and side mod

FIGURE 24o

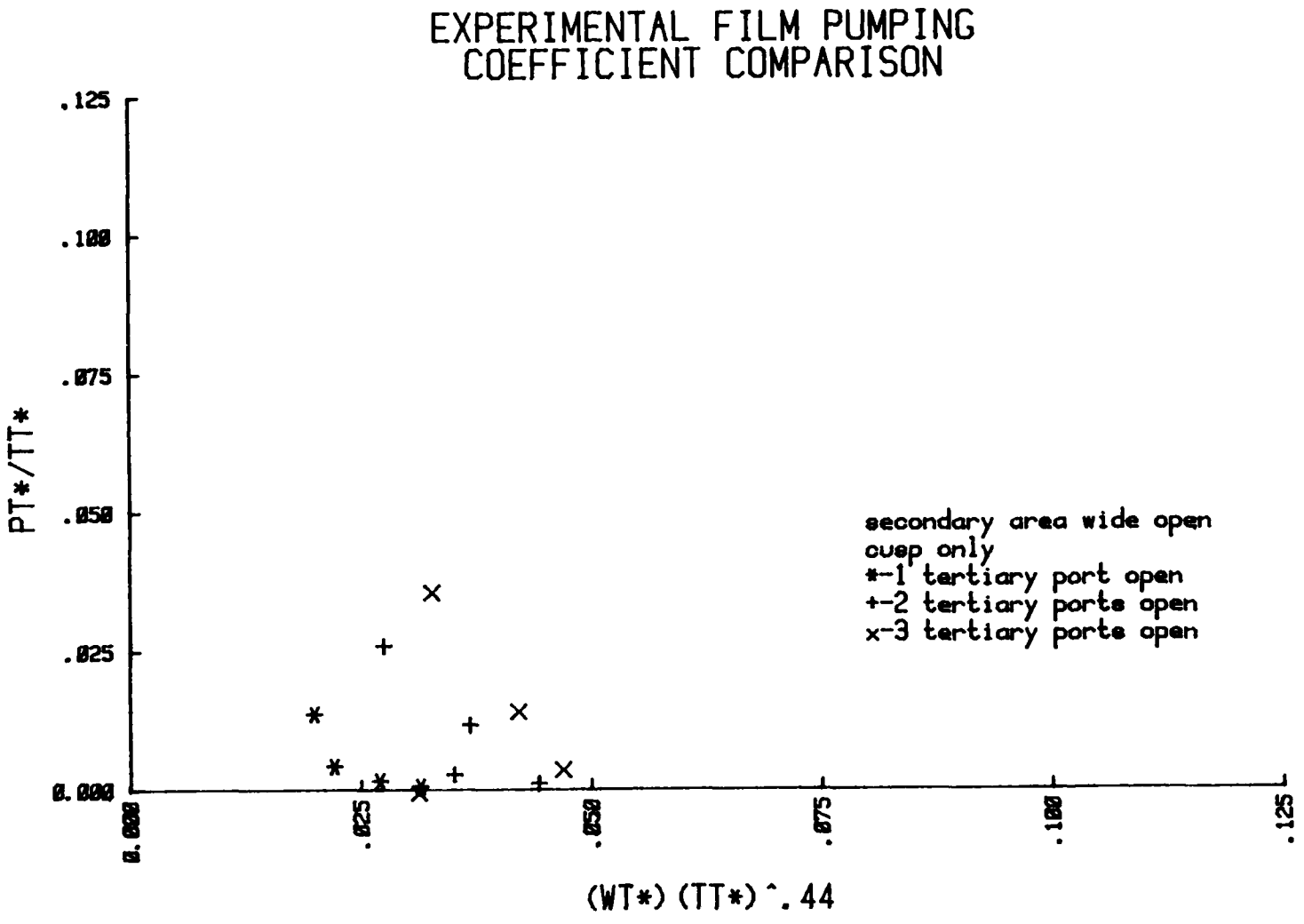

EXPERIMENTAL FILM PUMPING
COEFFICIENT COMPARISON
.125
.100
.075
.050
.025
0.000
PT*/TT*
secondary area wide open
cusp only
*-1 tertiary port open
+-2 tertiary ports open
x-3 tertiary ports open
0.000
.025
.050
.075
.100
.125
(WT*) (TT*) ^. 44

FIGURE 25a

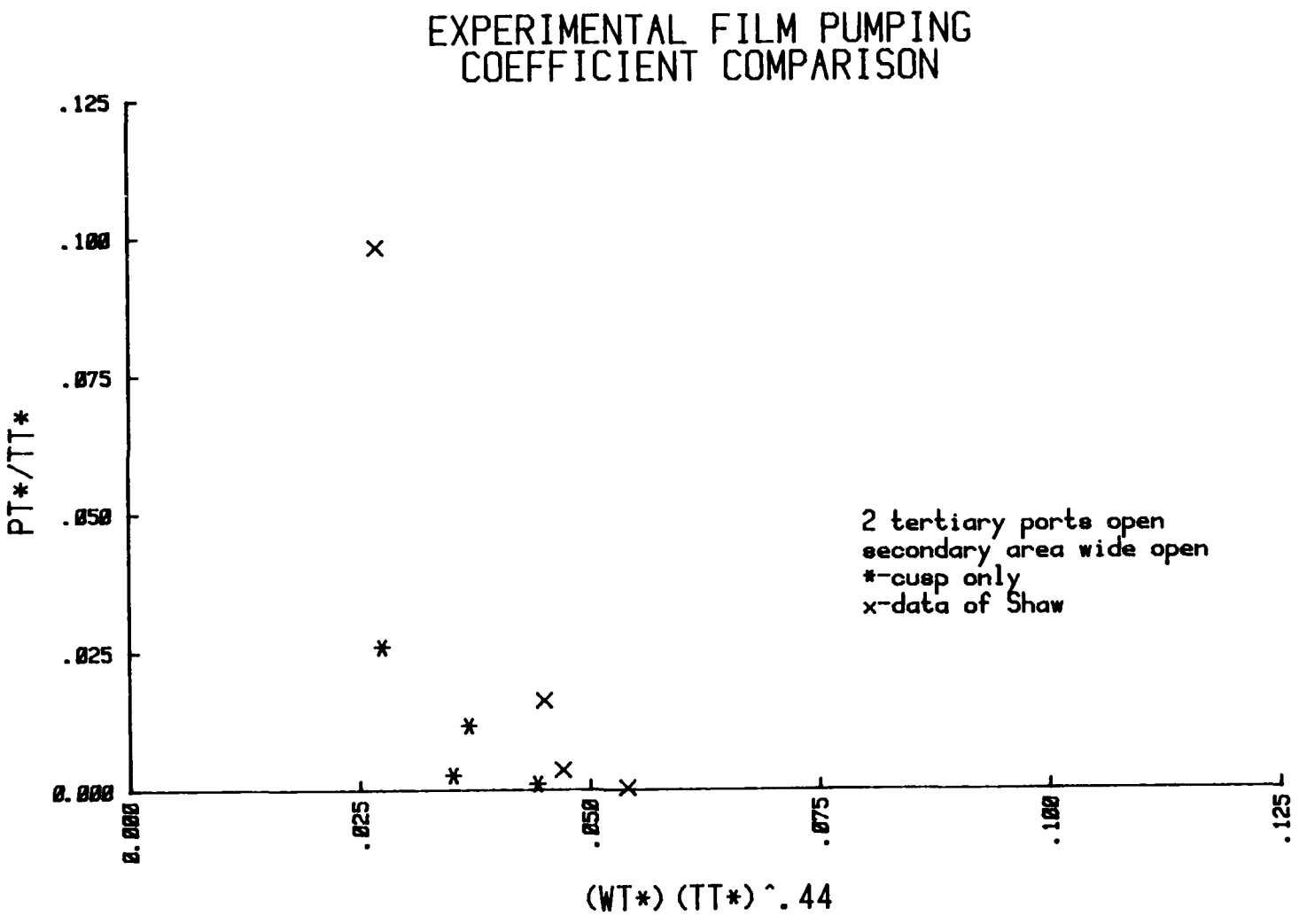

EXPERIMENTAL FILM PUMPING
COEFFICIENT COMPARISON
.125
.100
.075
.050
.025
0.000
PT*/TT*
2 tertiary ports open
secondary area wide open
*-cusp only
x-data of Shaw
0.000
.025
.050
.075
.100
.125
(WT*) (TT*) ^. 44

FIGURE 25b

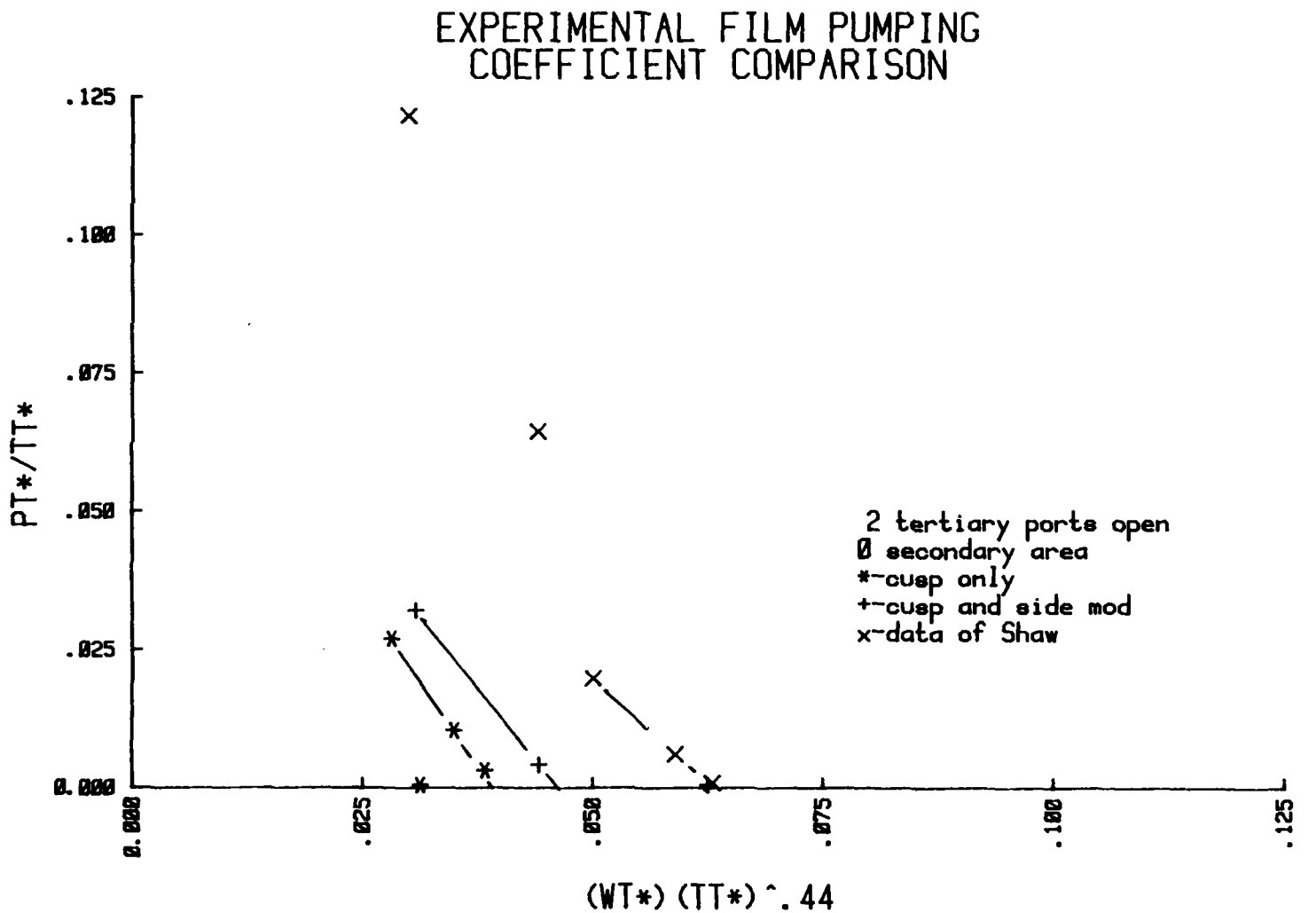

EXPERIMENTAL FILM PUMPING
COEFFICIENT COMPARISON
PT*/TT*
.125
.100
.075
.050
.025
0.000
0.000
.025
.050
.075
.100
.125
(WT*) (TT*) ^. 44
2 tertiary ports open
Ø secondary area
*-cusp only
+-cusp and side mod
x-data of Shaw

FIGURE 25c

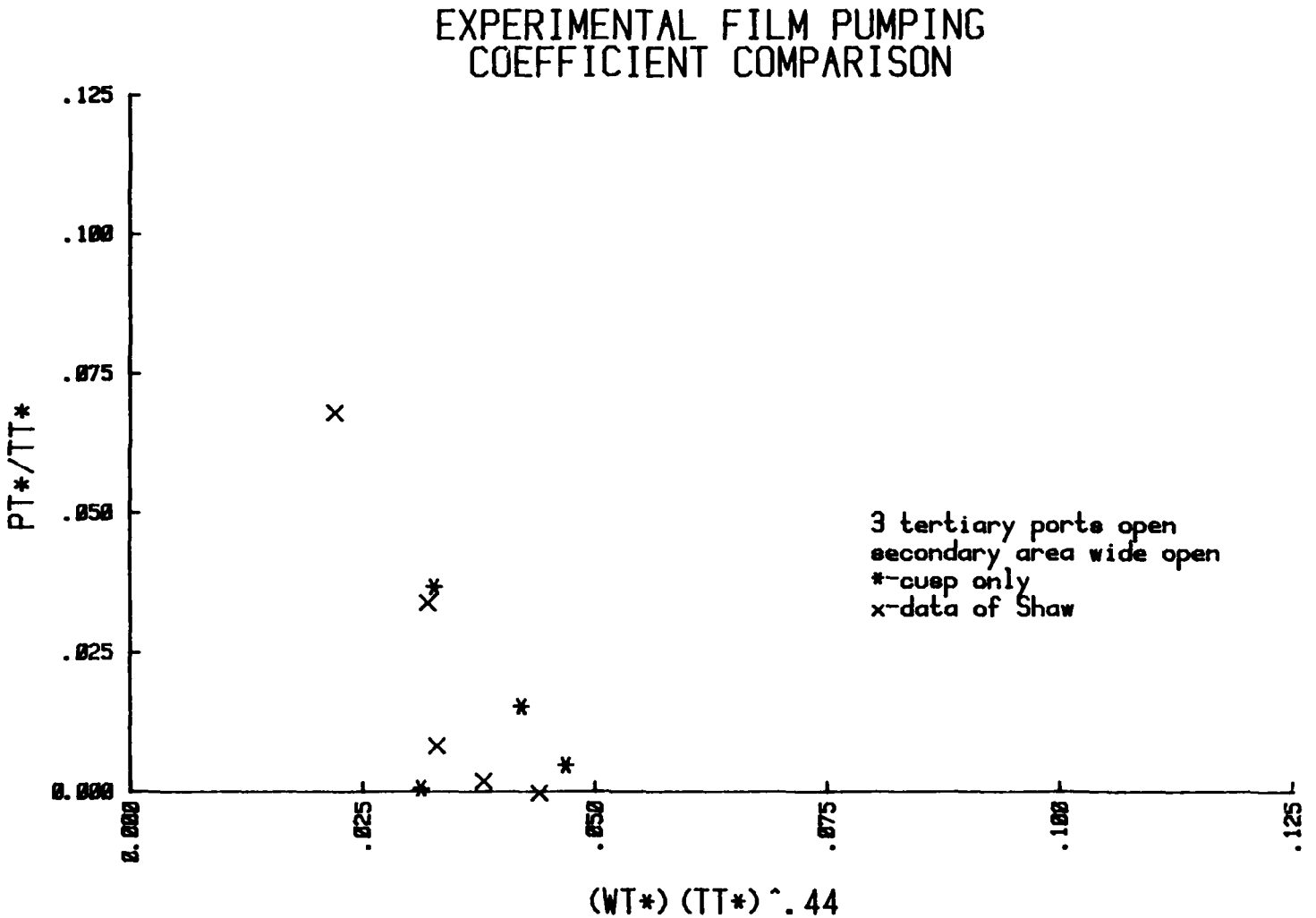

EXPERIMENTAL FILM PUMPING
COEFFICIENT COMPARISON
.125
.100
.075
.050
.025
0.000
PT*/TT*
3 tertiary ports open
secondary area wide open
*-cuep only
x-data of Shaw
0.000
.025
.050
.075
.100
.125
(WT*) (TT*) ^. 44

FIGURE 25d

# EXPERIMENTAL FILM PUMPING COEFFICIENT COMPARISON

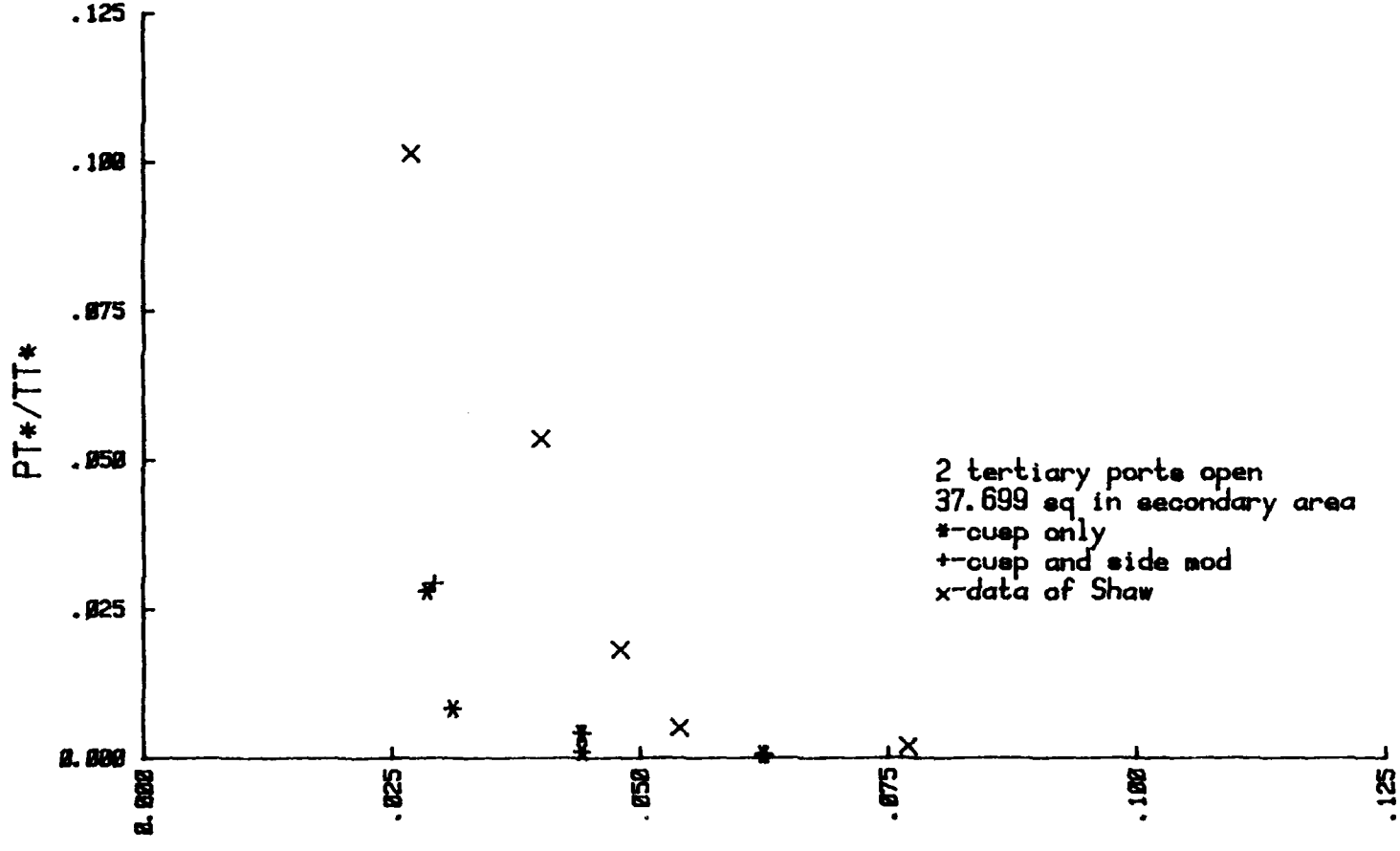



FIGURE 25e

# EXPERIMENTAL FILM PUMPING COEFFICIENT COMPARISON

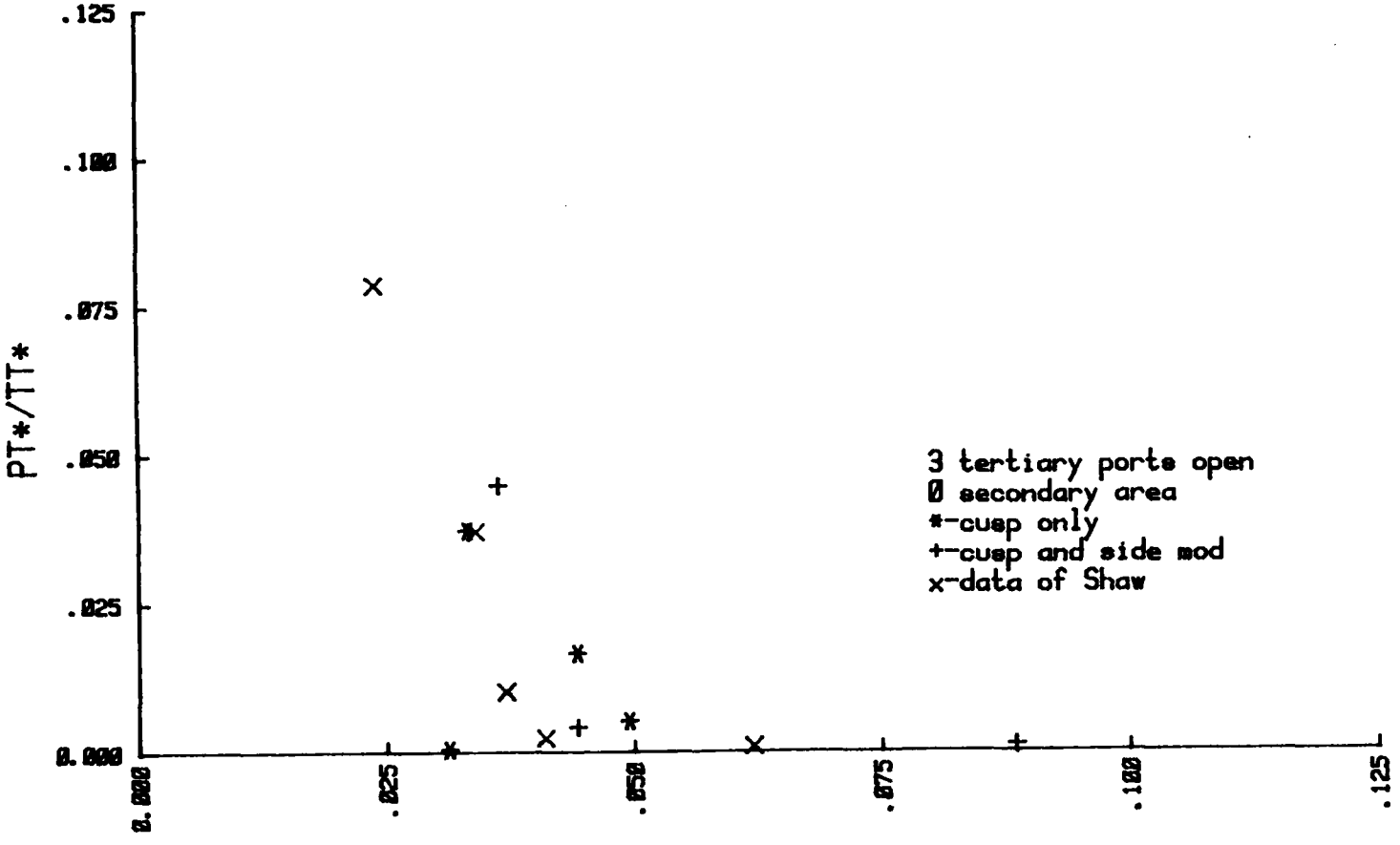



FIGURE 25f

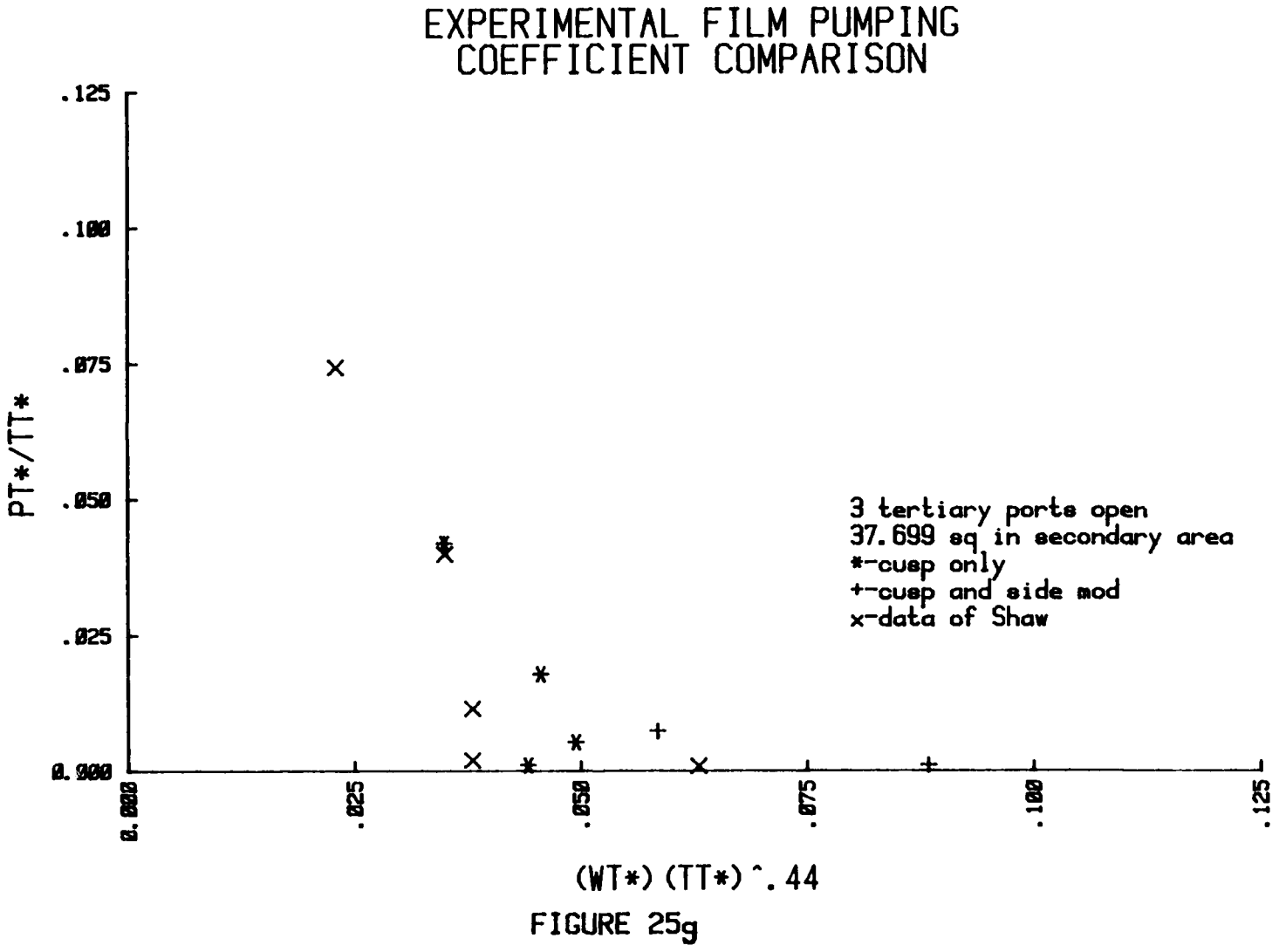

EXPERIMENTAL FILM PUMPING
COEFFICIENT COMPARISON
PT*/TT*
.125
.100
.075
.050
.025
0.000
.025
.050
.075
.100
.125
(WT*) (TT*) ^.44
3 tertiary ports open
37.699 sq in secondary area
*-cusp only
+-cusp and side mod
x-data of Shaw

FIGURE 25g

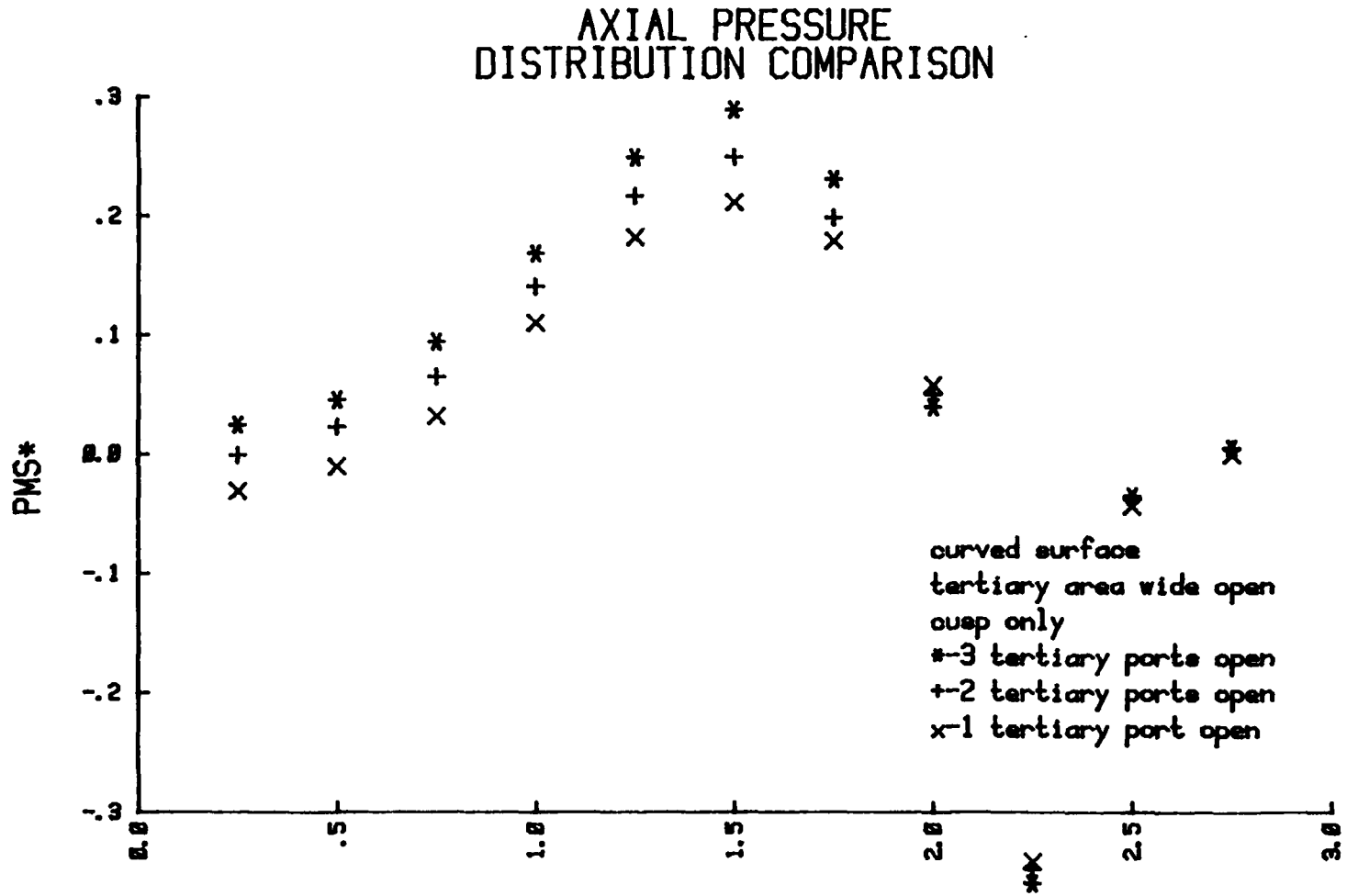

AXIAL PRESSURE
DISTRIBUTION COMPARISON
PMS*
.3
.2
.1
0.0
-.1
-.2
-.3
0.0
.5
1.0
1.5
2.0
2.5
3.0
curved surface
tertiary area wide open
cusp only
*-3 tertiary ports open
+-2 tertiary ports open
x-1 tertiary port open
AXIAL DISTANCE (X/S)

FIGURE 26a

# AXIAL PRESSURE DISTRIBUTION COMPARISON

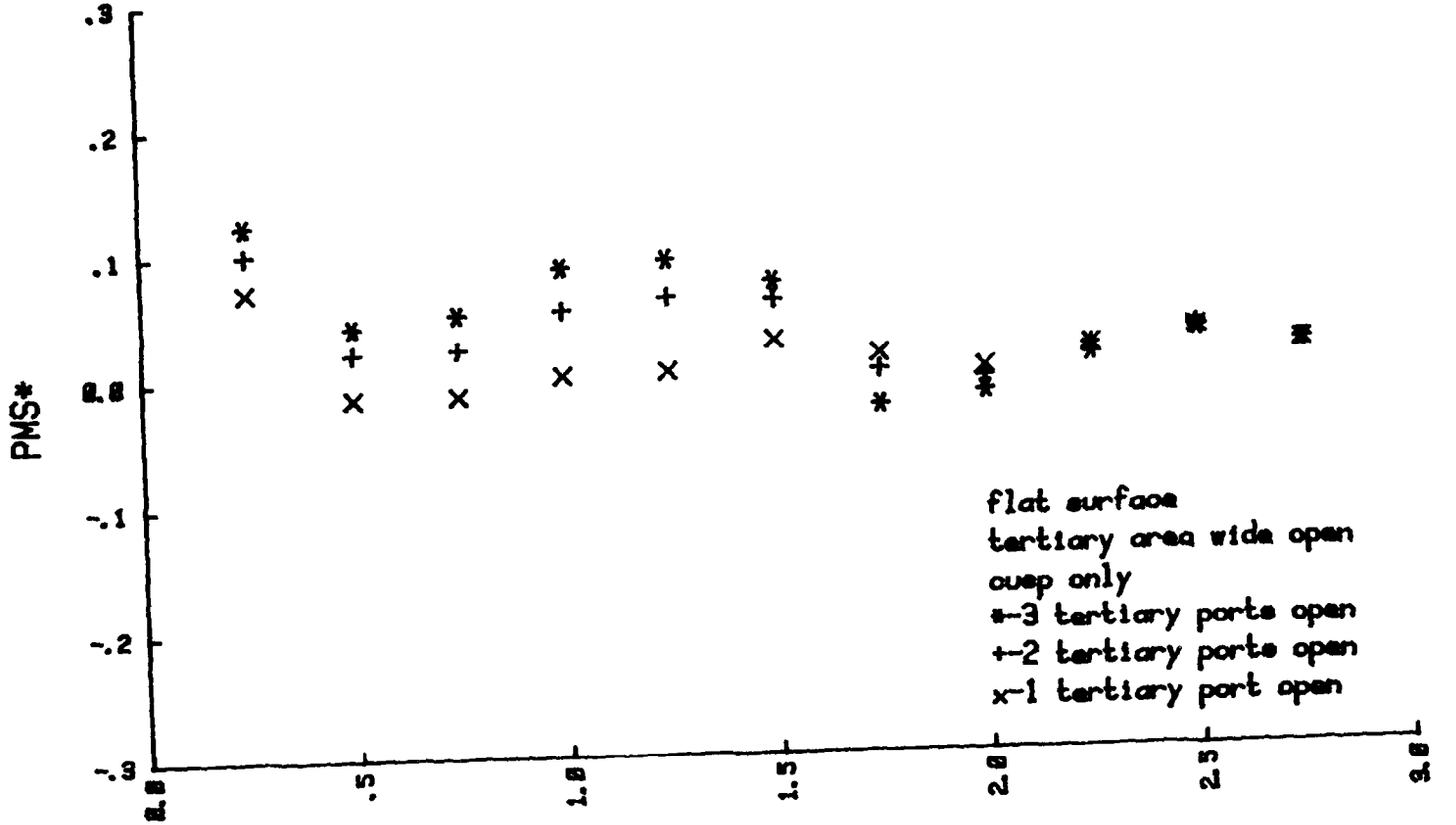



FIGURE 26b

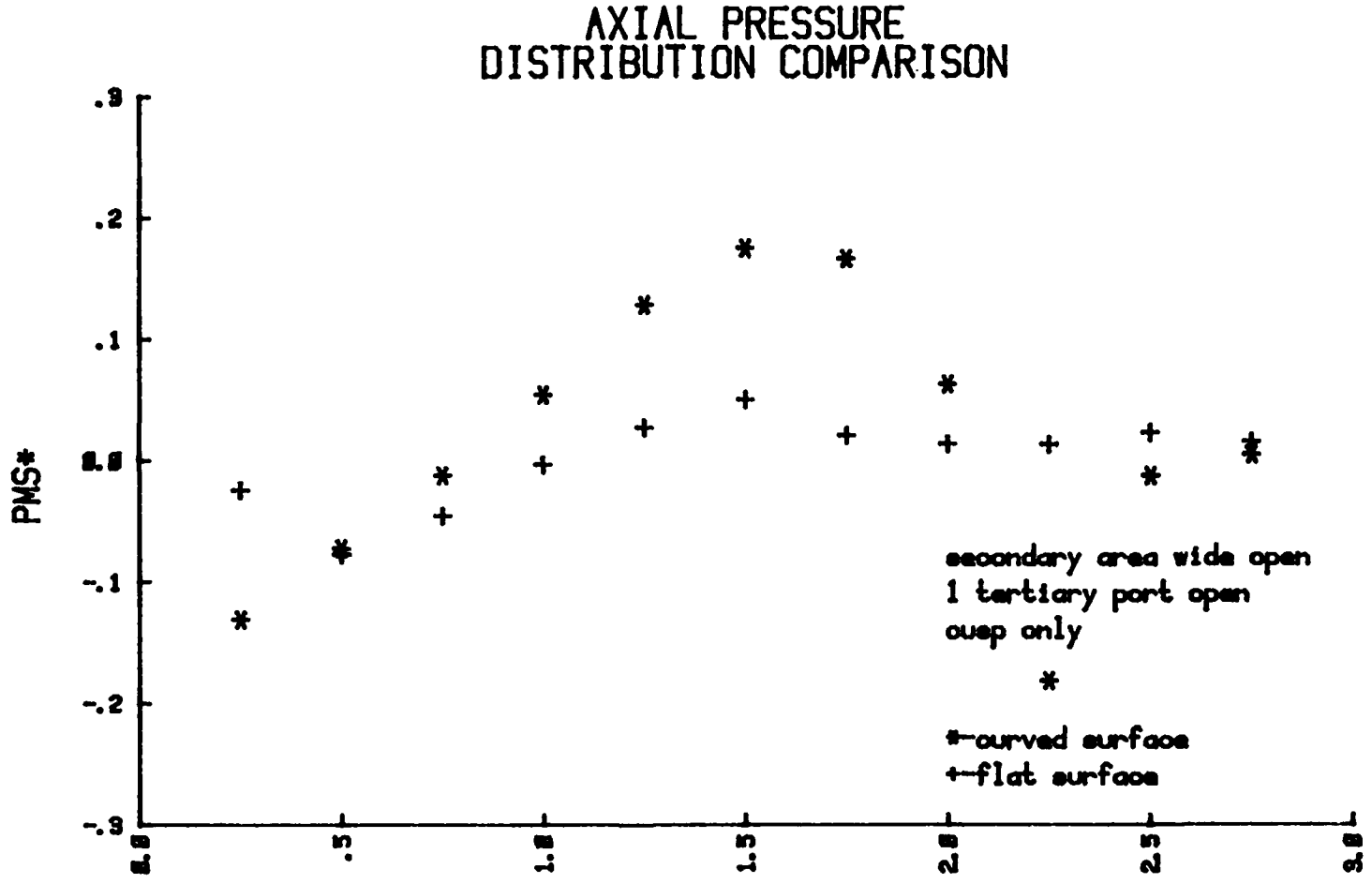

AXIAL PRESSURE
DISTRIBUTION COMPARISON
PMS*
.3
.2
.1
-.1
-.2
-.3
secondary area wide open
1 tertiary port open
ouep only
*-curved surface
+-flat surface
AXIAL DISTANCE (X/S)

FIGURE 26a

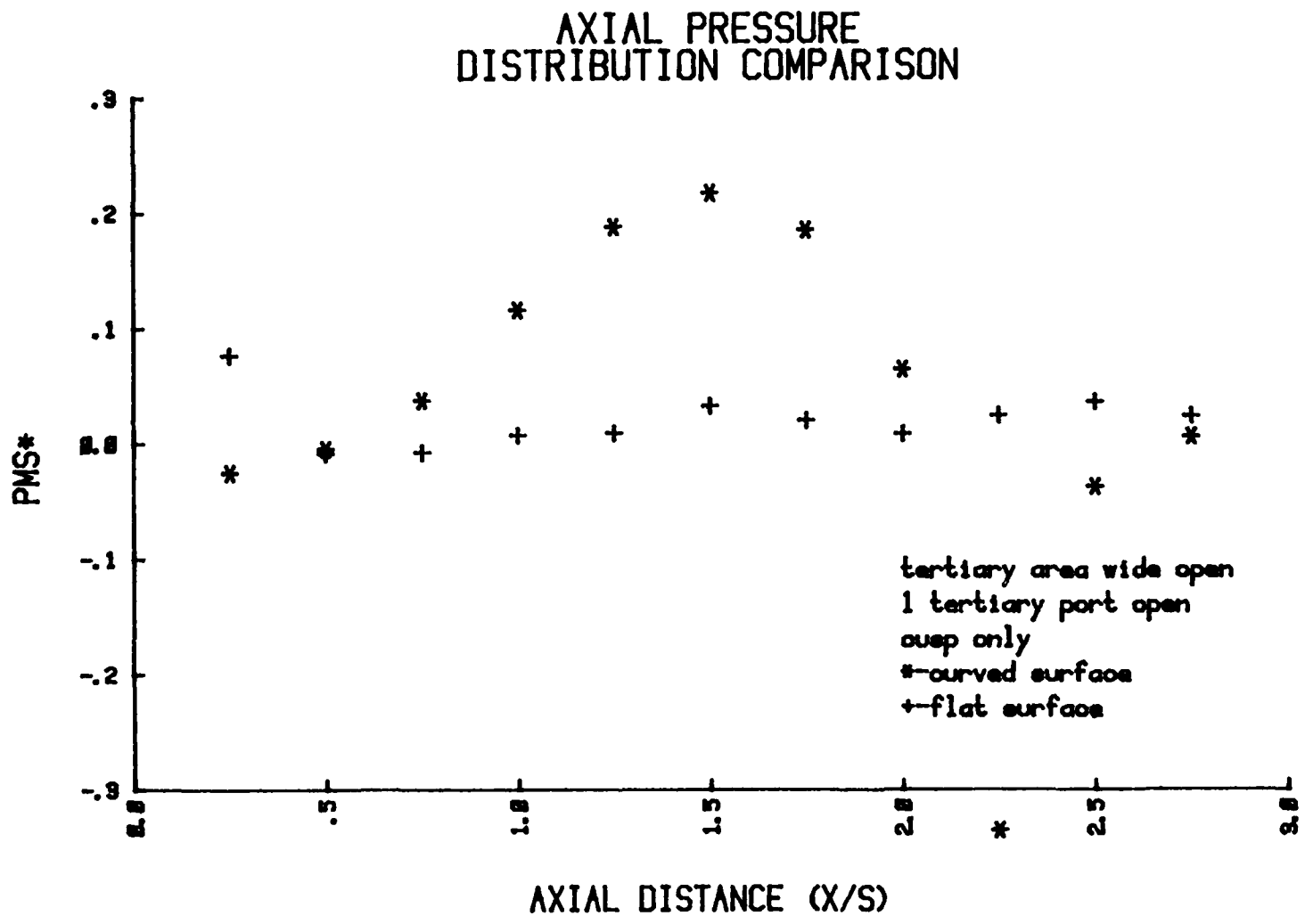

AXIAL PRESSURE
DISTRIBUTION COMPARISON
PMS*
.3
.2
.1
.0
-.1
-.2
-.3
.5
1.0
1.5
2.0
2.5
3.0
AXIAL DISTANCE (X/S)
tertiary area wide open
1 tertiary port open
ouep only
*-curved surface
+-flat surface

FIGURE 26d

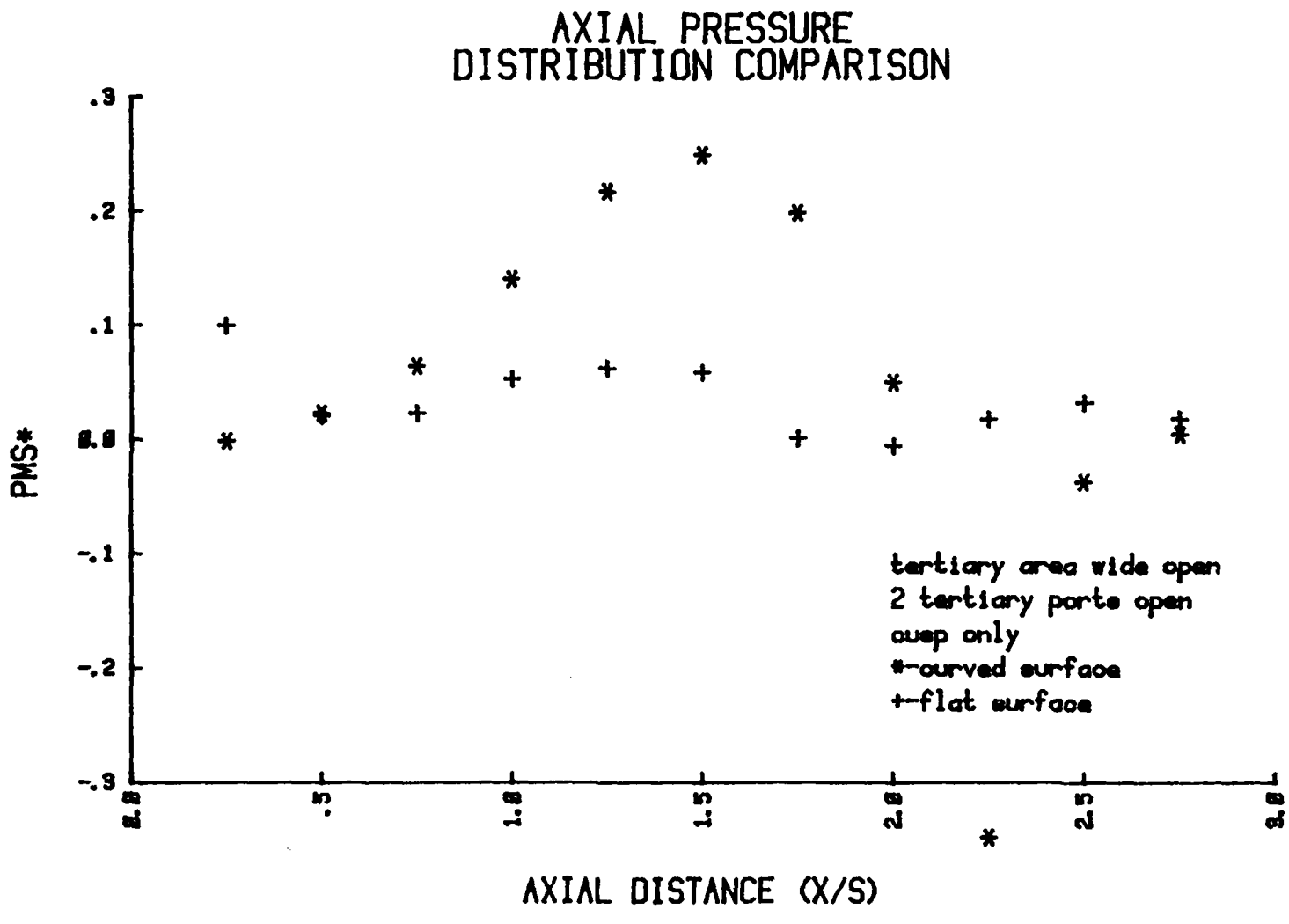

AXIAL PRESSURE
DISTRIBUTION COMPARISON
.3
.2
.1
0.0
-.1
-.2
-.3
PMS*
0.0
.5
1.0
1.5
2.0
2.5
3.0
tertiary area wide open
2 tertiary ports open
cusp only
*-curved surface
+-flat surface
AXIAL DISTANCE (X/S)

FIGURE 26e

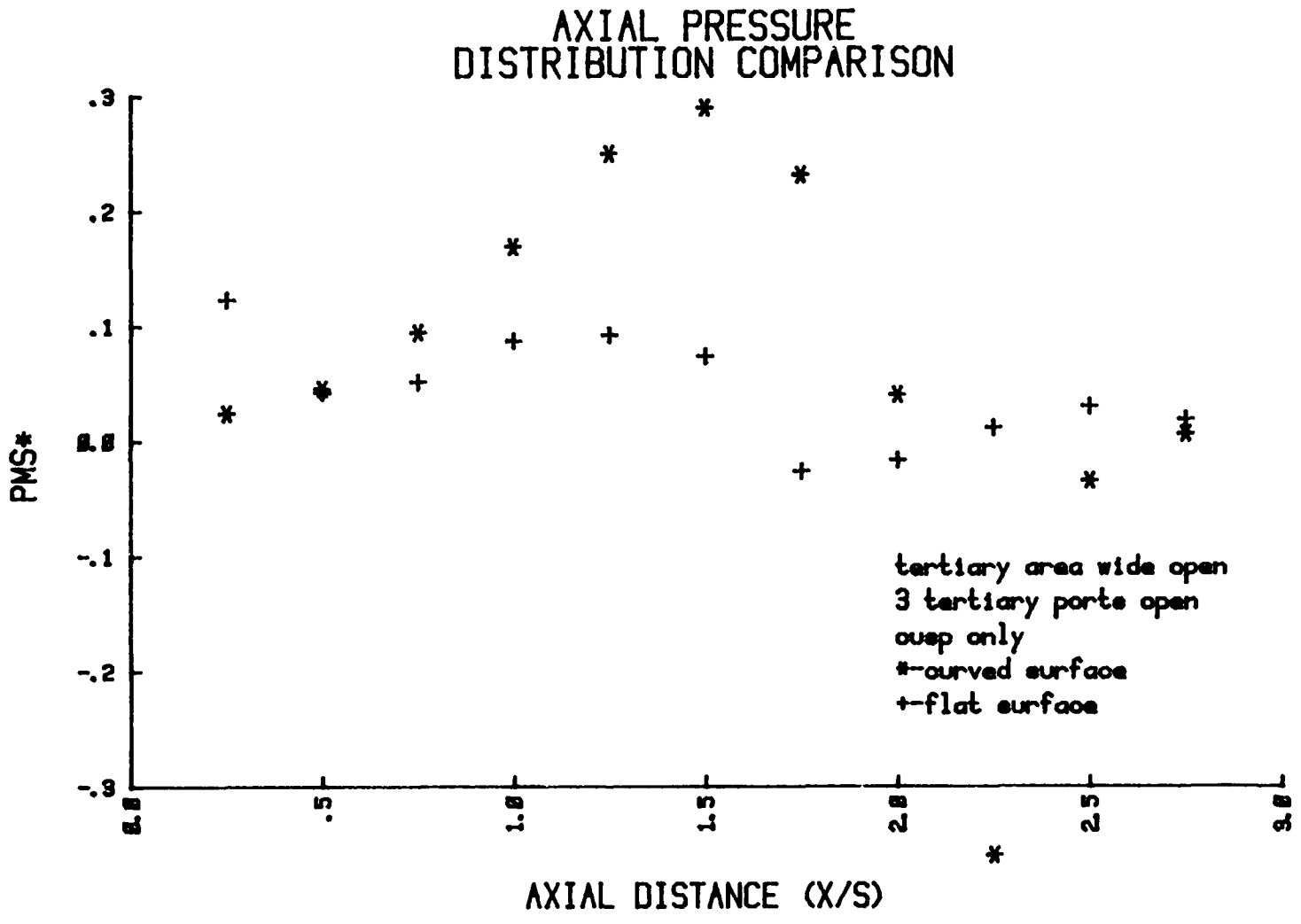

AXIAL PRESSURE
DISTRIBUTION COMPARISON
PMS*
.3
.2
.1
-.1
-.2
-.3
.5
1.0
1.5
2.0
2.5
tertiary area wide open
3 tertiary ports open
ouep only
*-curved surface
+-flat surface
AXIAL DISTANCE (X/S)

FIGURE 26f

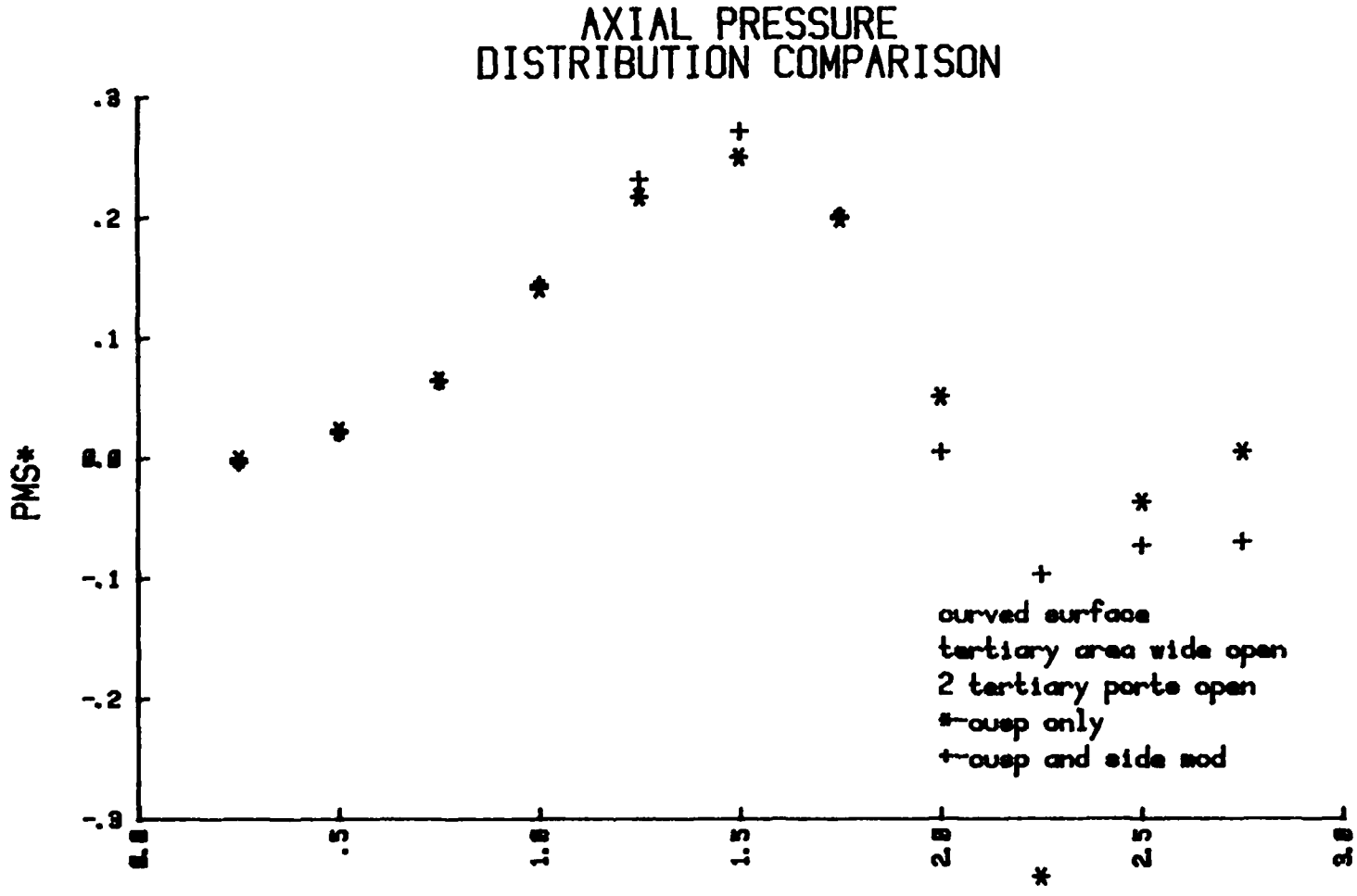

AXIAL PRESSURE
DISTRIBUTION COMPARISON
PMS*
.3
.2
.1
-.1
-.2
-.3
.5
1.5
2.5
curved surface
tertiary area wide open
2 tertiary ports open
*-ouep only
+-ouep and side mod
AXIAL DISTANCE (X/S)

FIGURE 26g

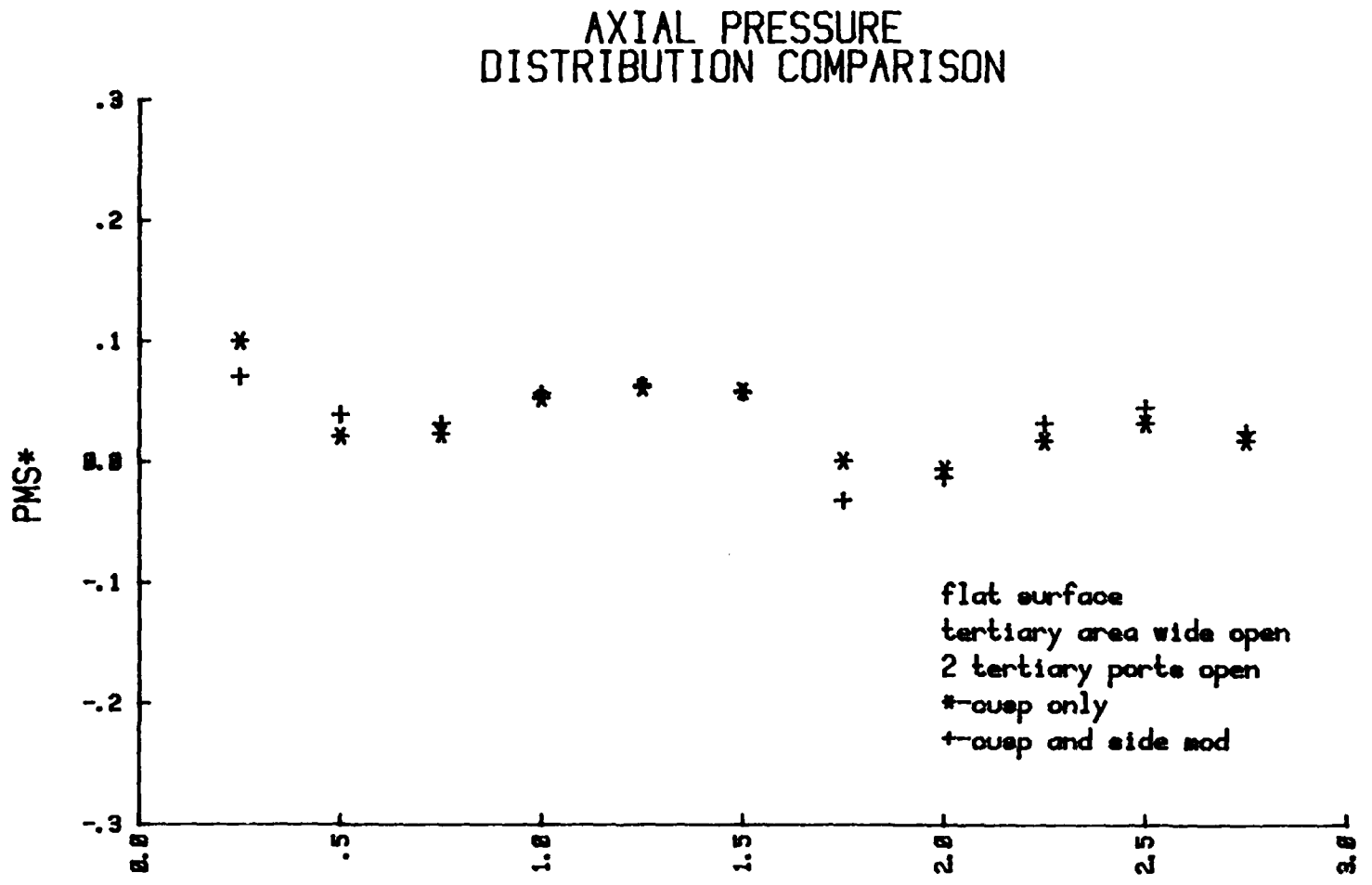

AXIAL PRESSURE
DISTRIBUTION COMPARISON
PMS*
.3
.2
.1
0.0
-.1
-.2
-.3
0.0
.5
1.0
1.5
2.0
2.5
3.0
flat surface
tertiary area wide open
2 tertiary ports open
*-cusp only
+-cusp and side mod
AXIAL DISTANCE (X/S)

FIGURE 26h

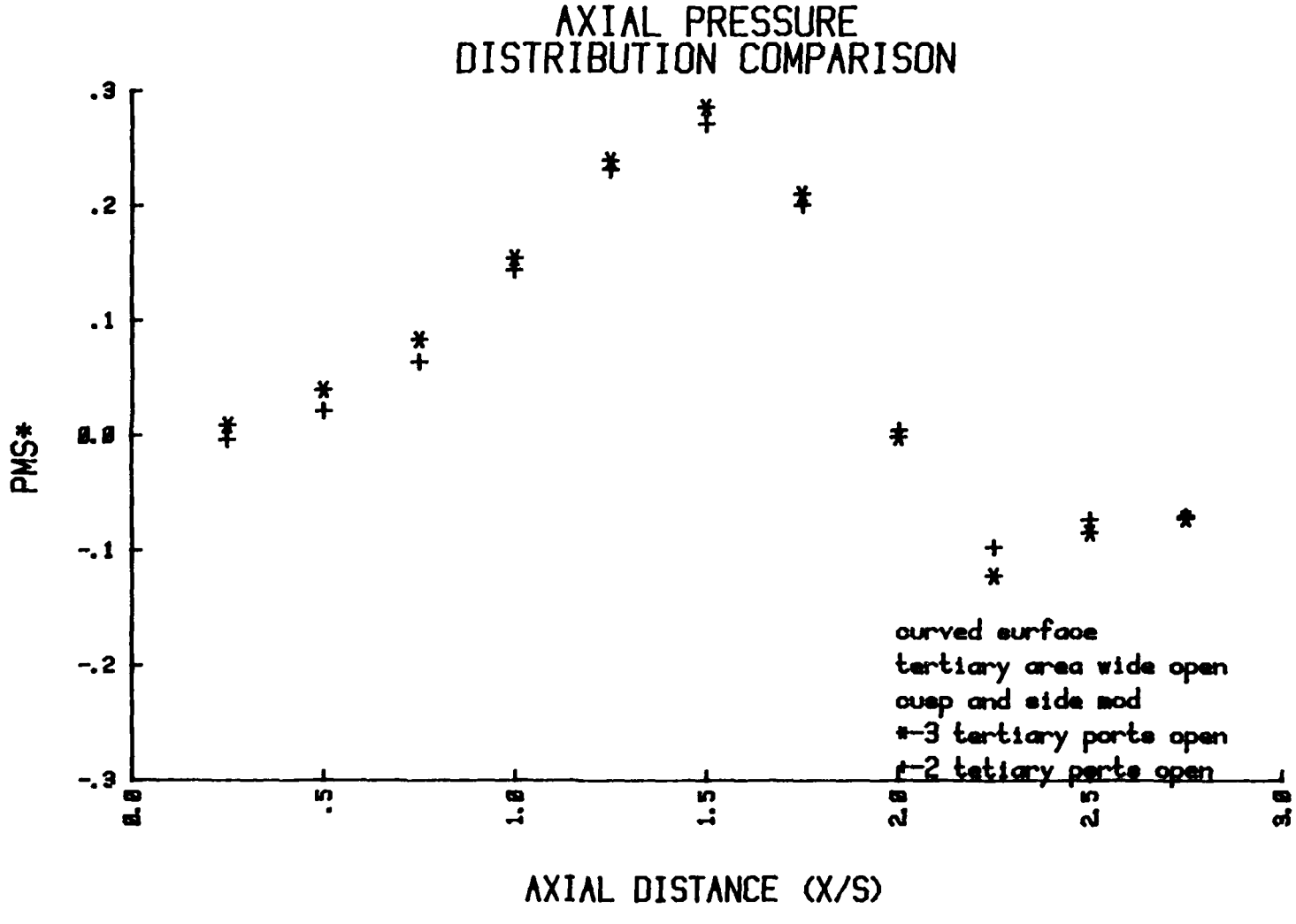

AXIAL PRESSURE
DISTRIBUTION COMPARISON
PMS*
.3
.2
.1
-.1
-.2
-.3
.5
1.0
1.5
2.0
2.5
3.0
curved surface
tertiary area wide open
cusp and side mod
*-3 tertiary ports open
+-2 tetiary ports open
AXIAL DISTANCE (X/S)

FIGURE 26i

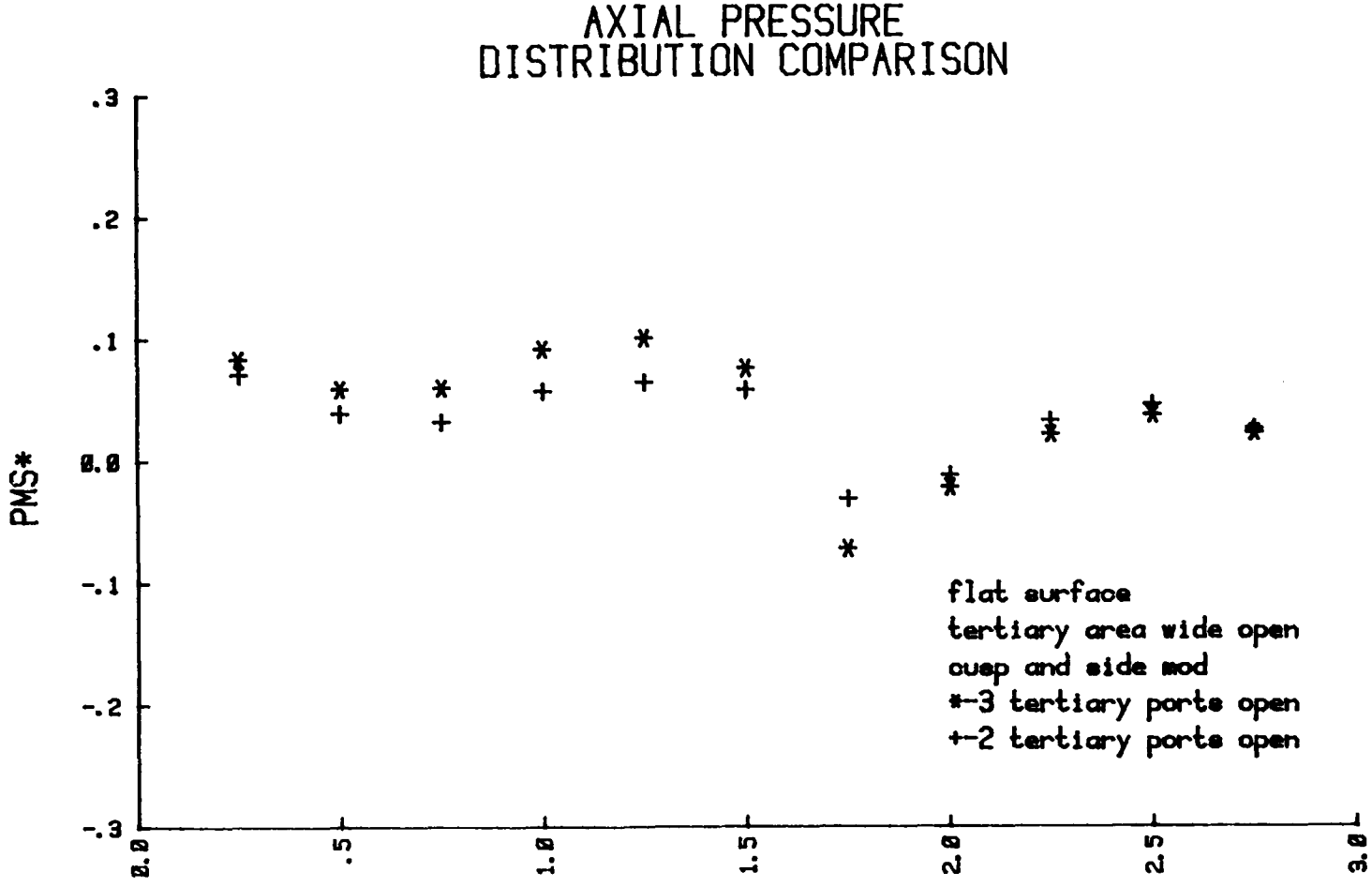

AXIAL PRESSURE
DISTRIBUTION COMPARISON
PMS*
.3
.2
.1
0.0
-.1
-.2
-.3
0.0
.5
1.0
1.5
2.0
2.5
3.0
AXIAL DISTANCE (X/S)
flat surface
tertiary area wide open
cuep and side mod
*-3 tertiary ports open
+-2 tertiary ports open

FIGURE 26j

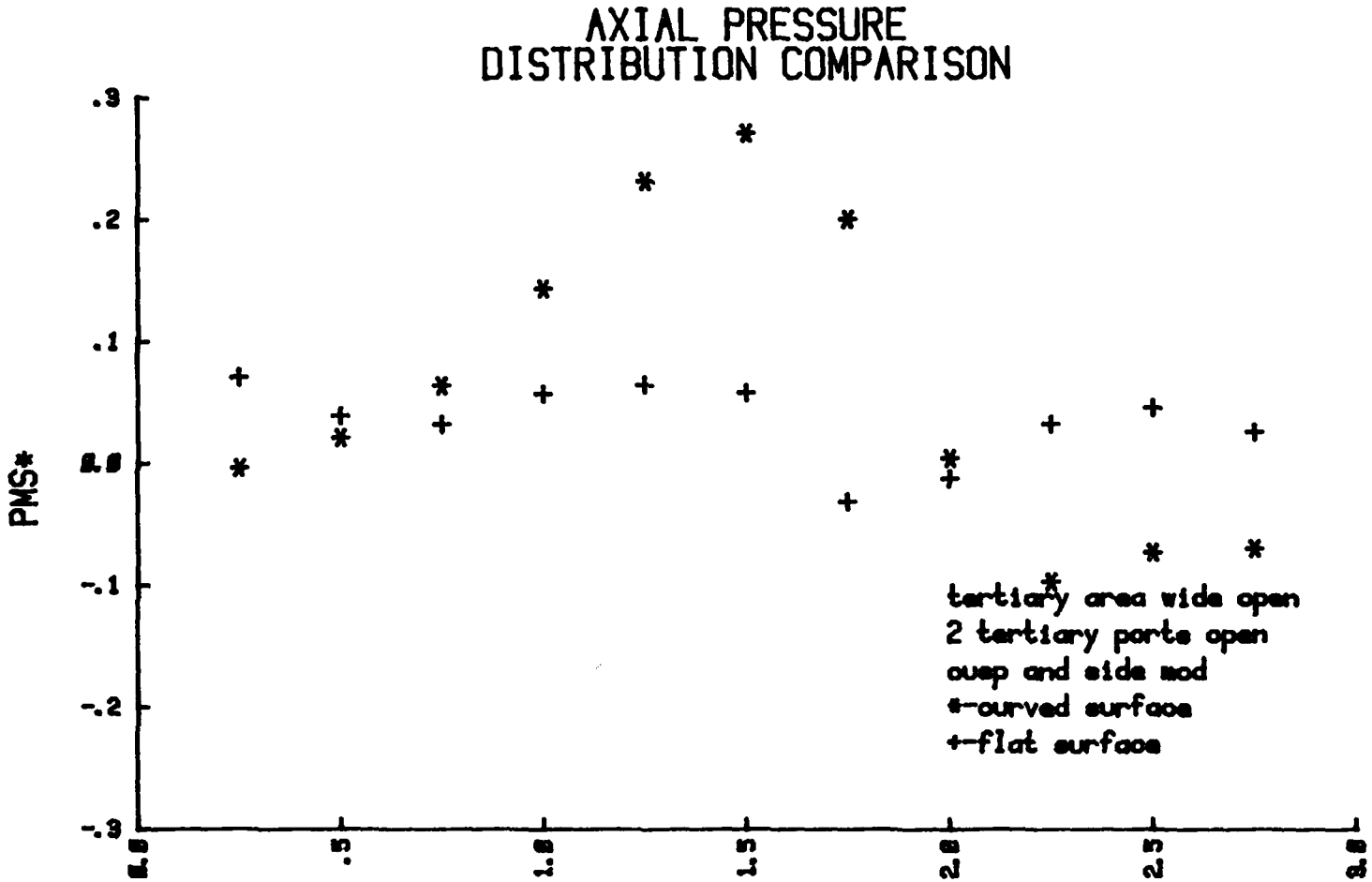

AXIAL PRESSURE
DISTRIBUTION COMPARISON
PMS*
.3
.2
.1
-.1
-.2
-.3
.5
1.5
2.5
tertiary area wide open
2 tertiary ports open
ouep and side mod
*-curved surface
+-flat surface
AXIAL DISTANCE (X/S)

FIGURE 28k

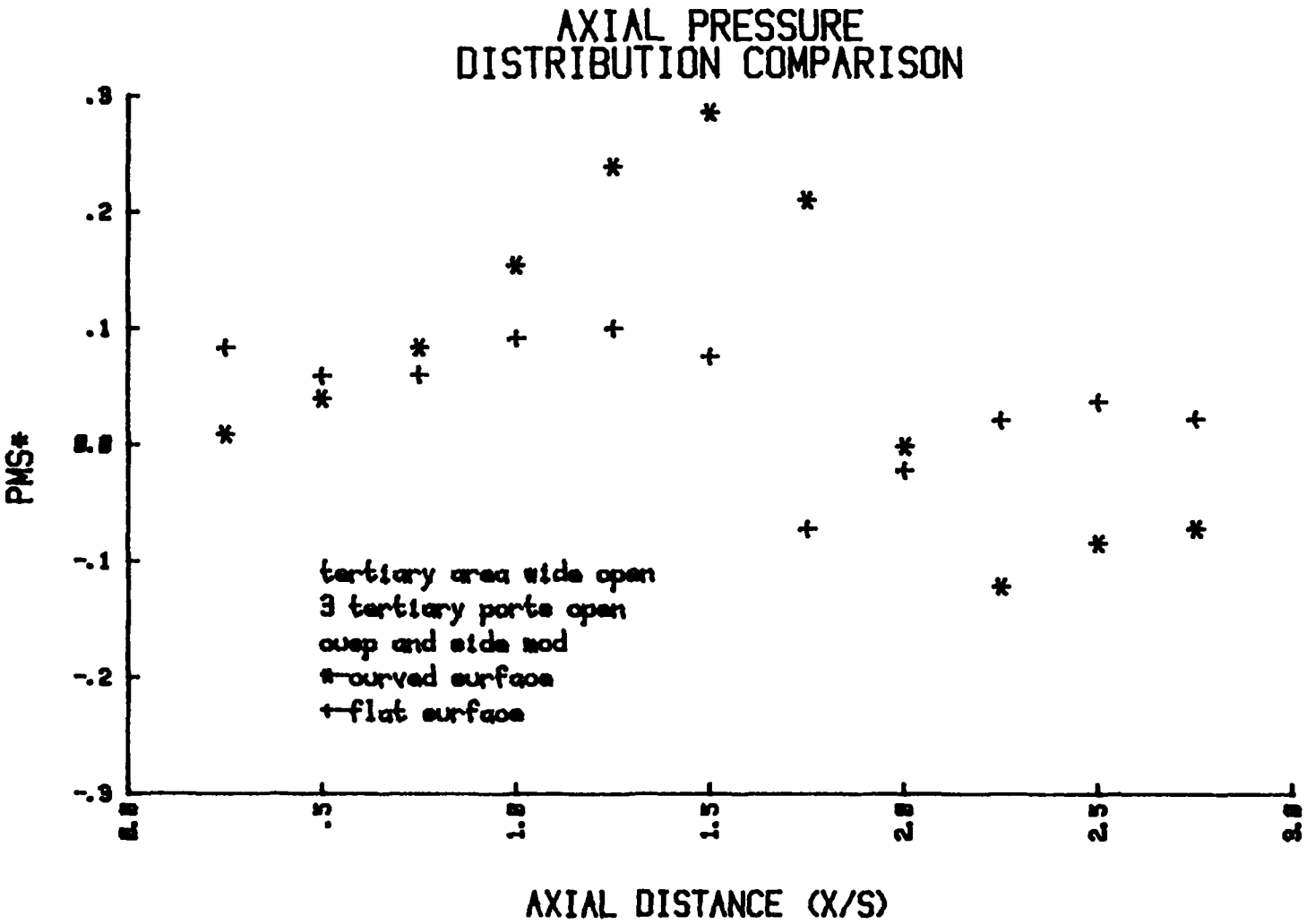

AXIAL PRESSURE
DISTRIBUTION COMPARISON
PMS*
.3
.2
.1
0.0
-.1
-.2
-.3
.5
1.0
1.5
2.0
2.5
tertiary area wide open
3 tertiary ports open
sweep and side mod
*-curved surface
+-flat surface
AXIAL DISTANCE (X/S)

FIGURE 261

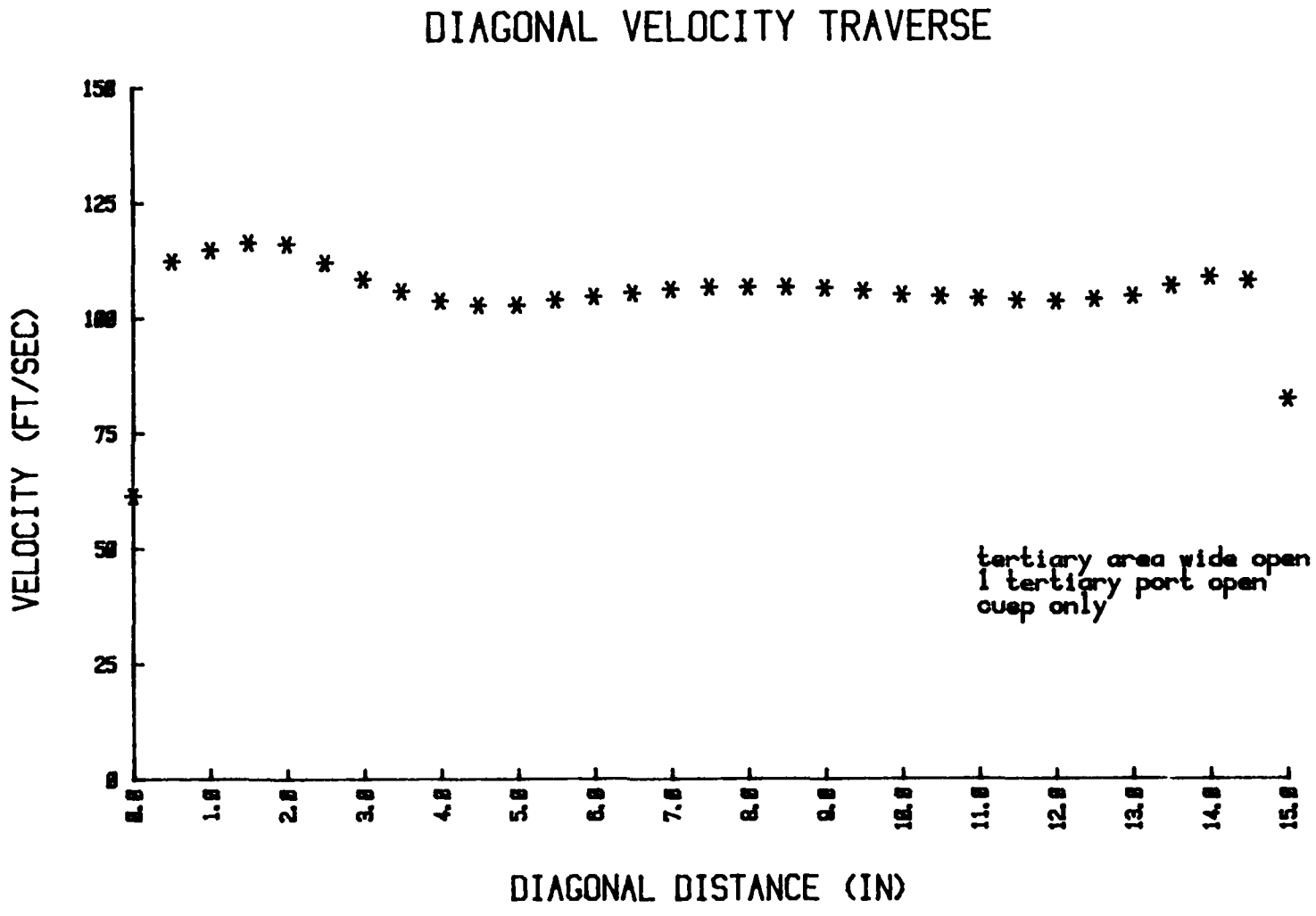

DIAGONAL VELOCITY TRAVERSE
VELOCITY (FT/SEC)
150
125
100
75
50
25
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
tertiary area wide open
1 tertiary port open
cusp only
DIAGONAL DISTANCE (IN)

FIGURE 27a

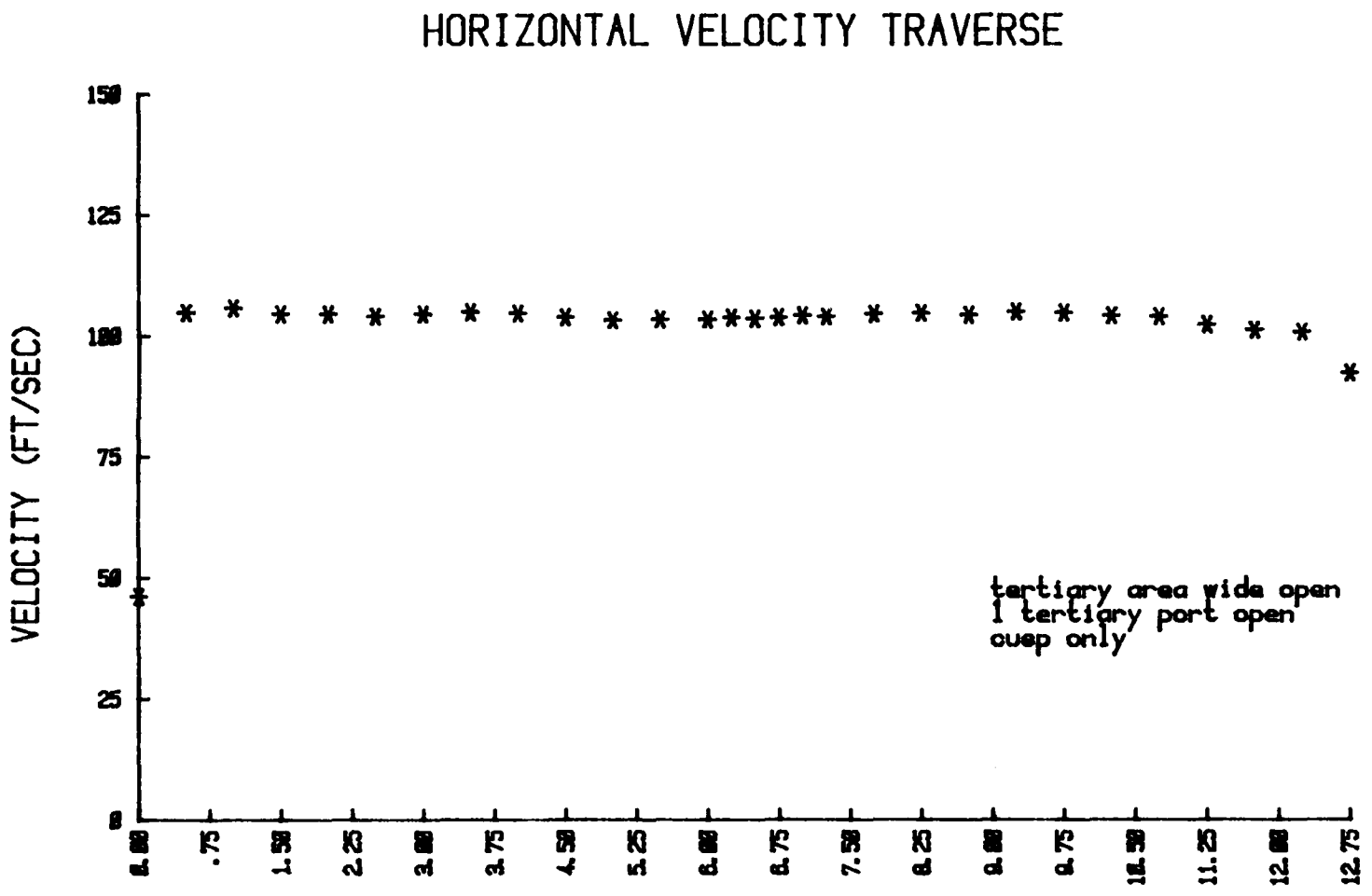

HORIZONTAL VELOCITY TRAVERSE
VELOCITY (FT/SEC)
150
125
100
75
50
25
0
.75
1.50
2.25
3.00
3.75
4.50
5.25
6.00
6.75
7.50
8.25
9.00
9.75
10.50
11.25
12.00
12.75
tertiary area wide open
1 tertiary port open
cuep only
HORIZONTAL DISTANCE (IN)

FIGURE 27b

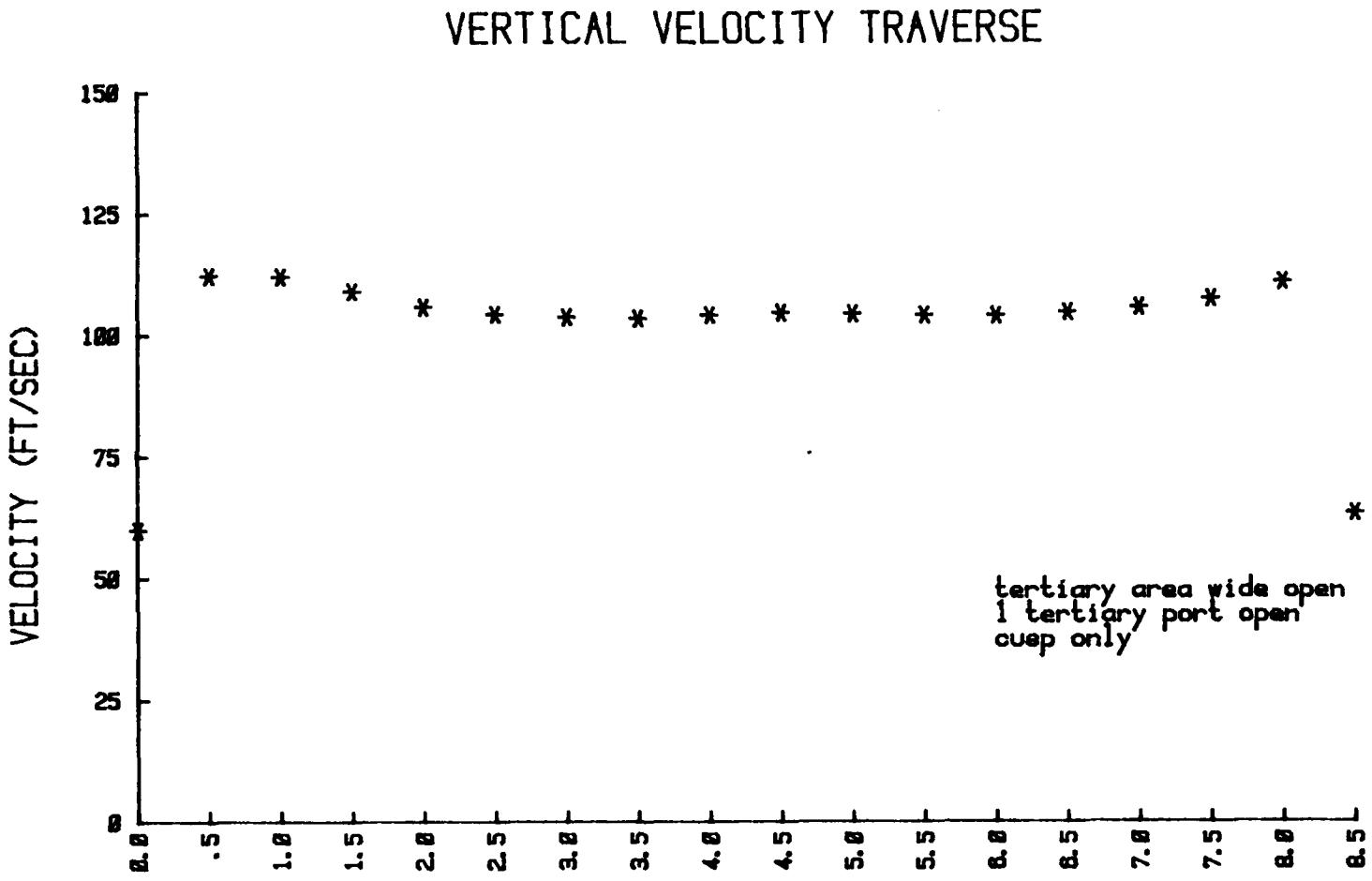

VERTICAL VELOCITY TRAVERSE
VELOCITY (FT/SEC)
150
125
100
75
50
25
0
0.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
tertiary area wide open
1 tertiary port open
cuep only
VERTICAL DISTANCE (IN)

FIGURE 27o

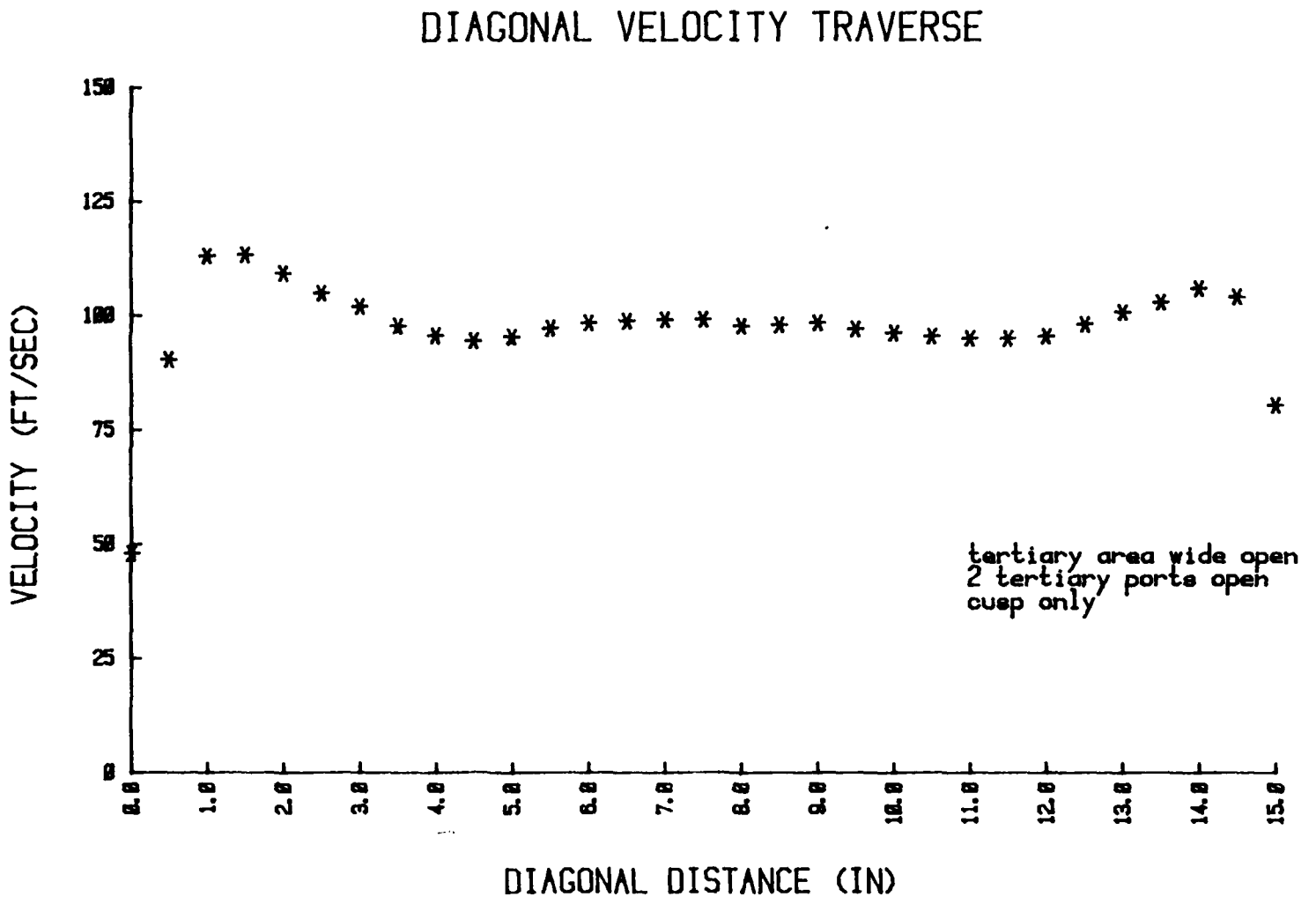

DIAGONAL VELOCITY TRAVERSE
VELOCITY (FT/SEC)
150
125
100
75
50
25
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
tertiary area wide open
2 tertiary ports open
cusp only
DIAGONAL DISTANCE (IN)

FIGURE 27d

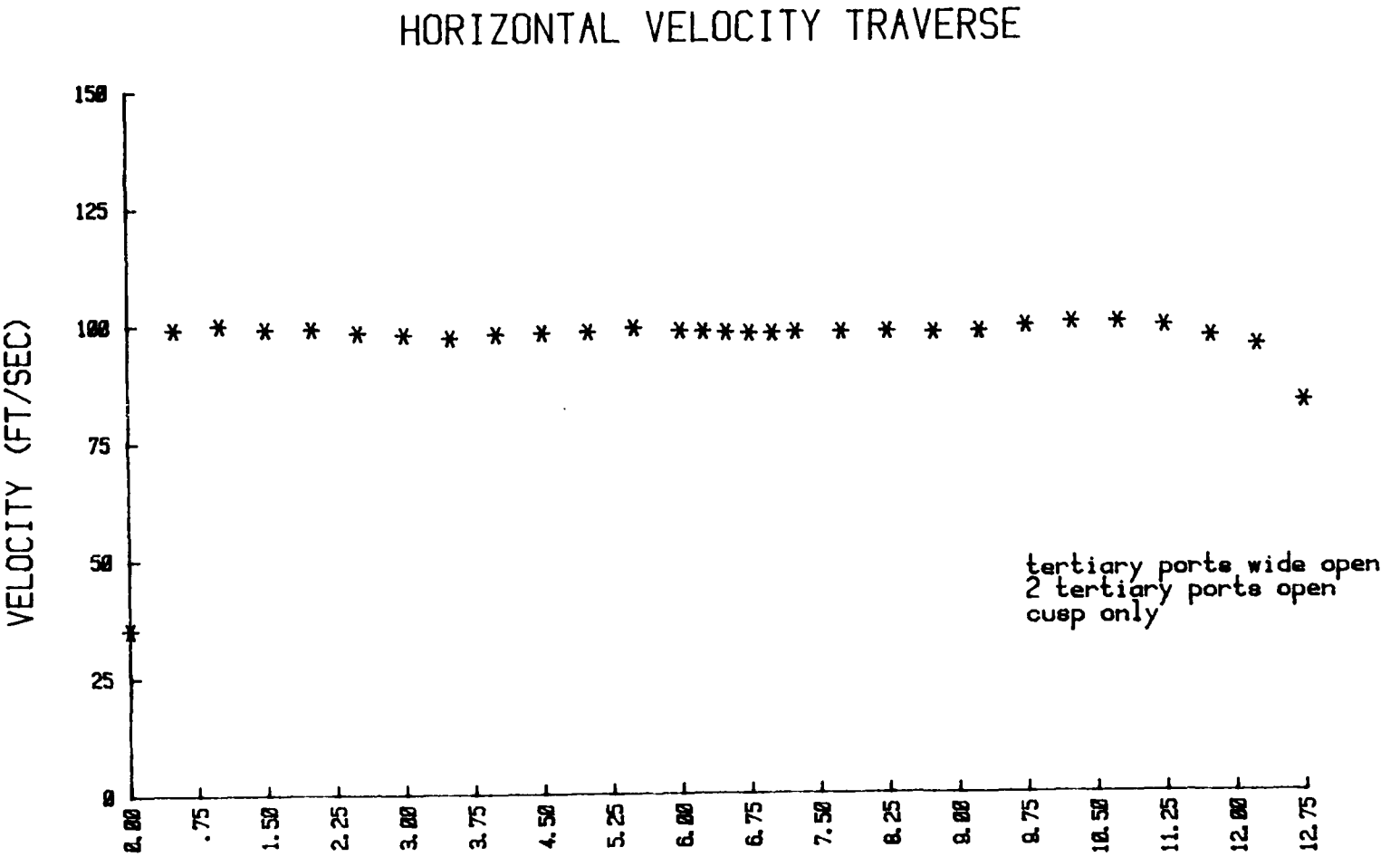

HORIZONTAL VELOCITY TRAVERSE
VELOCITY (FT/SEC)
150
125
100
75
50
25
0
0.00
.75
1.50
2.25
3.00
3.75
4.50
5.25
6.00
6.75
7.50
8.25
9.00
9.75
10.50
11.25
12.00
12.75
HORIZONTAL DISTANCE (IN)
tertiary ports wide open
2 tertiary ports open
cusp only

FIGURE 27a

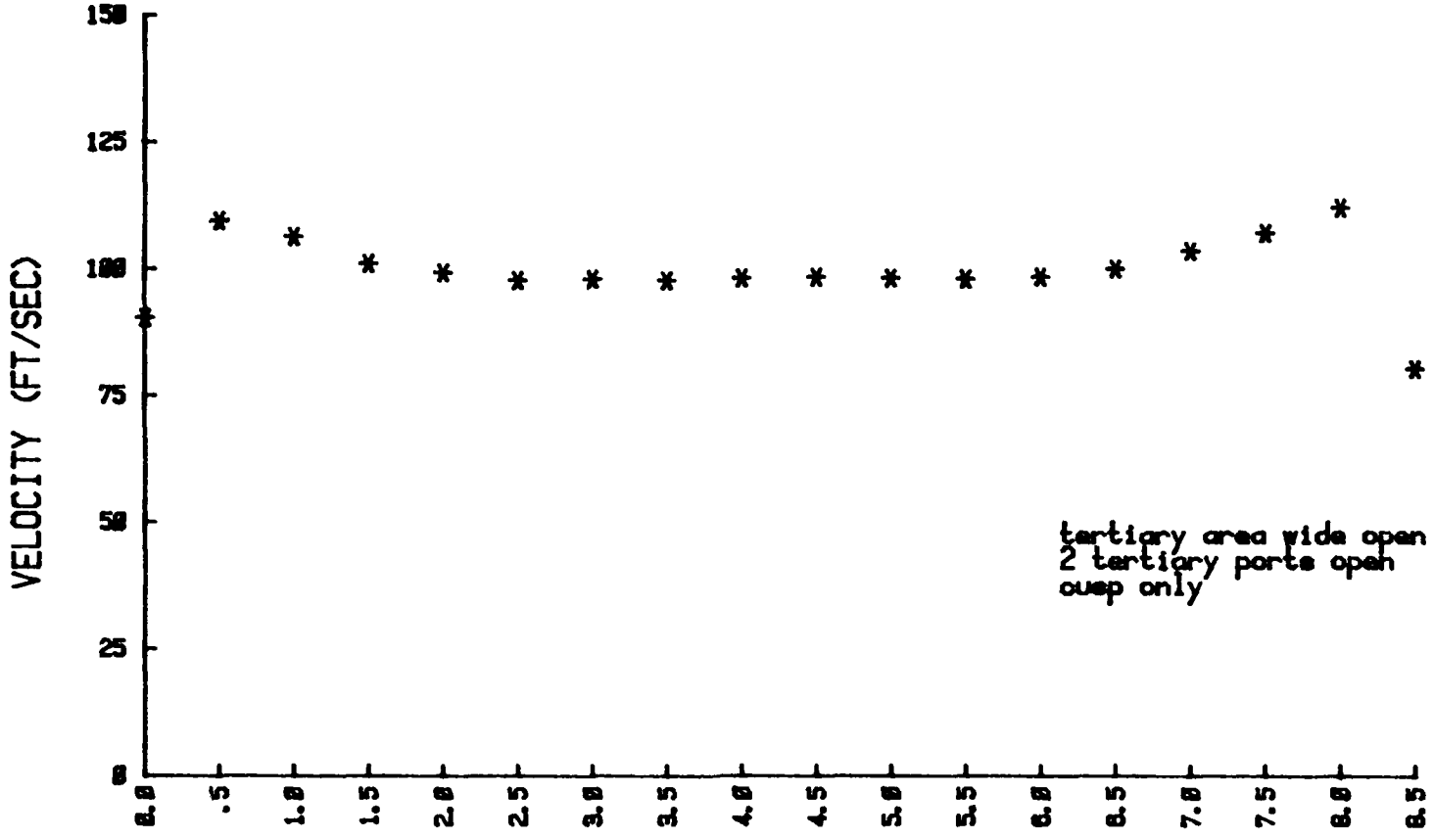

VERTICAL VELOCITY TRAVERSE
VELOCITY (FT/SEC)
150
125
100
75
50
25
0
0.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
VERTICAL DISTANCE (IN)
tertiary area wide open
2 tertiary ports open
ouep only

FIGURE 27f

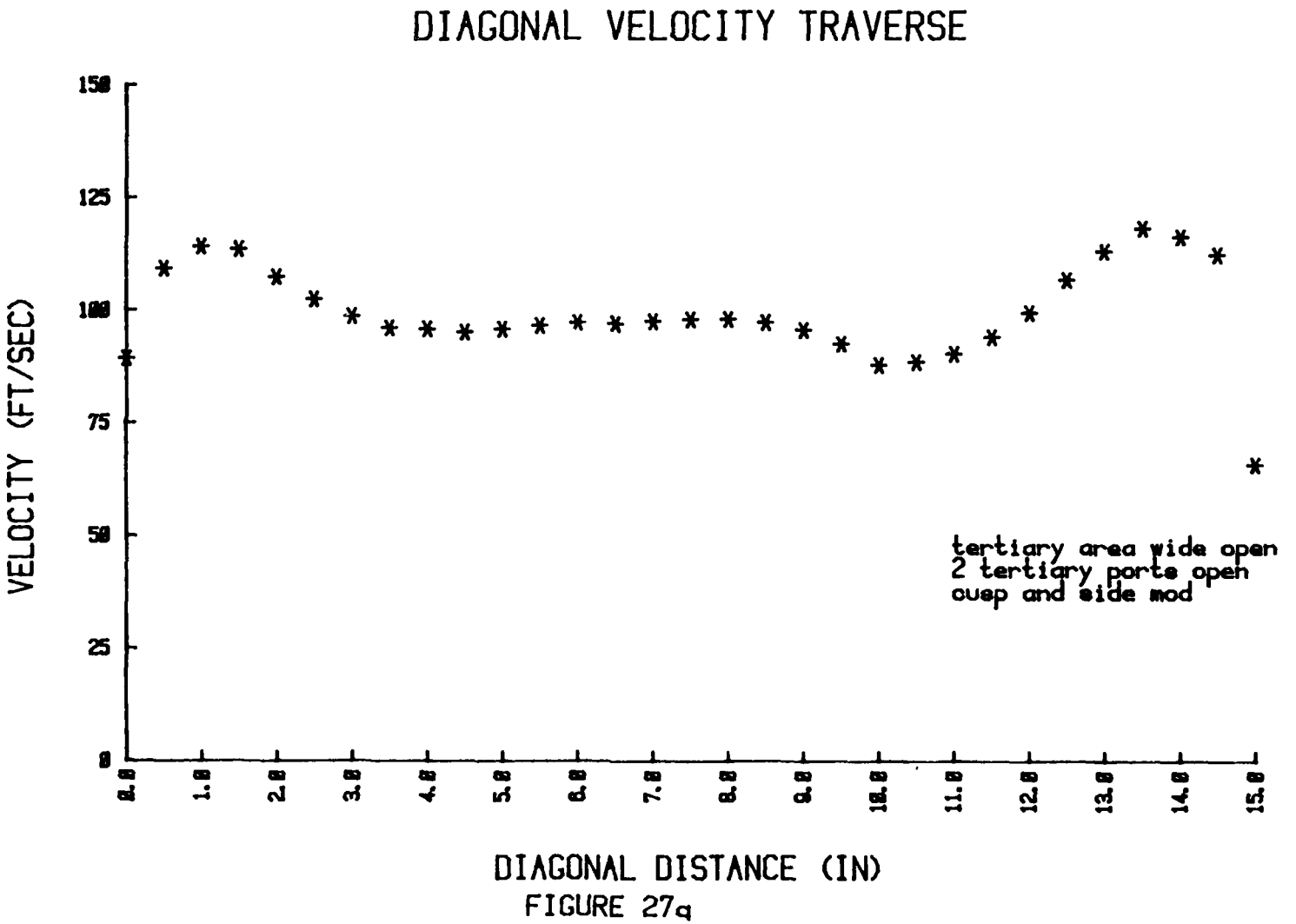
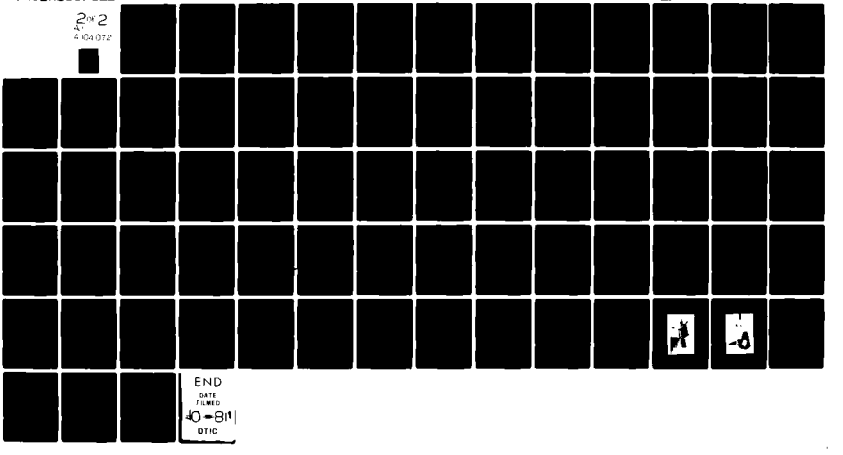

DIAGONAL VELOCITY TRAVERSE
VELOCITY (FT/SEC)
150
125
100
75
50
25
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
tertiary area wide open
2 tertiary ports open
cusp and side mod
DIAGONAL DISTANCE (IN)

FIGURE 27a

AD-A104 072 NAVAL POSTGRADUATE SCHOOL MONTEREY CA F/G 21/2
FLOW CHARACTERISTICS OF A MULTIPLE NOZZLE EXHAUST GAS EDUCTOR S--ETC(U)
MAR 81 D L RYAN

UNCLASSIFIED



END
DATE FILMED
10-81
DTIC

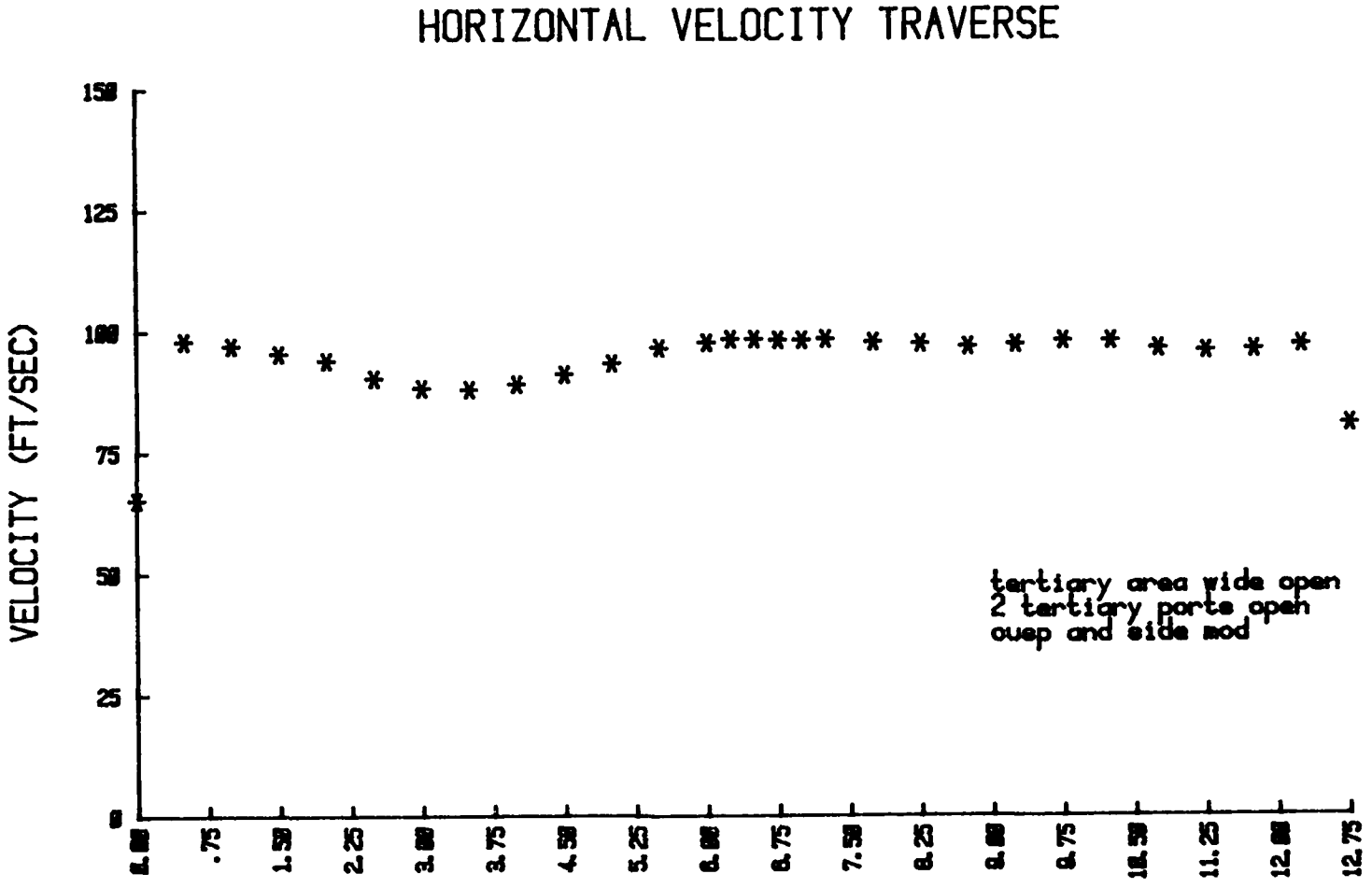

HORIZONTAL VELOCITY TRAVERSE
VELOCITY (FT/SEC)
150
125
100
75
50
25
0
tertiary area wide open
2 tertiary ports open
ouep and side mod
.75
1.50
2.25
3.00
3.75
4.50
5.25
6.00
6.75
7.50
8.25
9.00
9.75
10.50
11.25
12.00
12.75
HORIZONTAL DISTANCE (IN)

FIGURE 27h

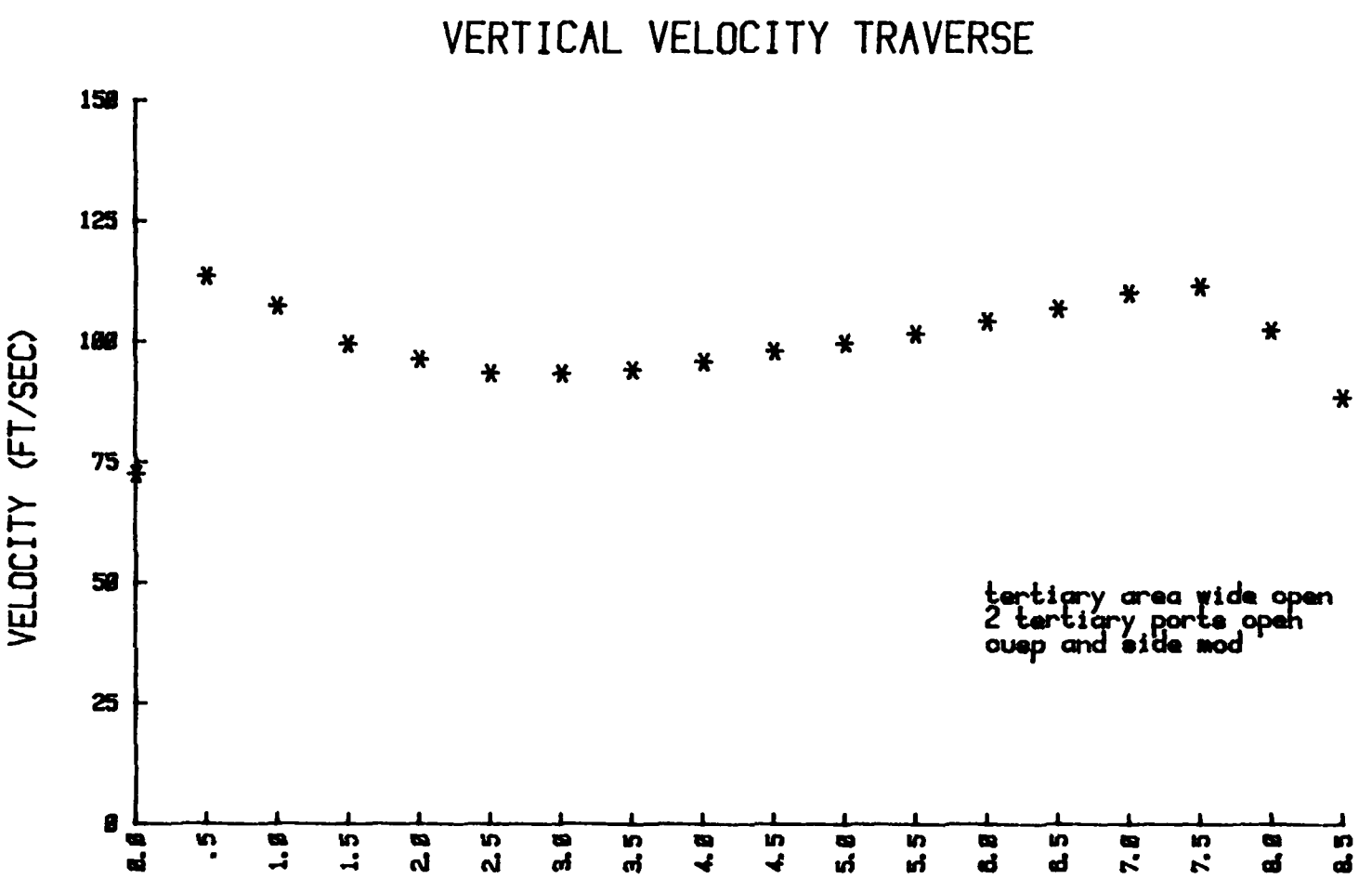

VERTICAL VELOCITY TRAVERSE
VELOCITY (FT/SEC)
150
125
100
75
50
25
0
0.0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
VERTICAL DISTANCE (IN)
tertiary area wide open
2 tertiary ports open
cusp and side mod

FIGURE 27i

DATA TAKEN ON 27 JANUARY 1981
DATA TAKEN BY D.L RYAN
3 TERTIARY PORTS OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA:107.51 SQ IN

PRIMARY NOZZLE AREA:9.06 SQ IN AREA RATIO (AM/AP): 2.99

MIXING STACK LENGTH:25.50 IN ORIFICE DIAMETER:6.908 IN

MIXING STACK DIMENSION: 8.5 IN ORIFICE BETA:0.497 IN

MIXING STACK L/S:3.00 AMBIENT PRESSURE:29.73 IN HG

| N | POR | DPOR | TOR | TUPT | TAMB | PU-PA | PA-PS | PA-PT | SECONDARY AREA | TERTIARY AREA |
|---|---|---|---|---|---|---|---|---|---|---|
| RUN | IN OF H2O | | DEGREES F | | | IN OF H2O | | | SQUARE INCHES | SQUARE INCHES |
| 1 | 0.7 | 22.1 | 51.3 | 102.9 | 55.0 | 7.70 | 2.41 | 0.00 | 0.000 | ******* |
| 2 | 0.7 | 21.8 | 50.0 | 103.3 | 55.0 | 8.20 | 1.82 | 0.00 | 6.283 | ******* |
| 3 | 0.8 | 22.2 | 48.9 | 103.2 | 55.0 | 9.00 | 1.42 | 0.00 | 12.566 | ******* |
| 4 | 0.7 | 21.8 | 49.9 | 104.0 | 55.0 | 9.05 | 0.82 | 0.01 | 25.133 | ******* |
| 5 | 0.7 | 21.8 | 49.8 | 104.3 | 55.0 | 9.50 | 0.32 | 0.01 | 50.265 | ******* |
| 6 | 0.7 | 21.9 | 50.8 | 104.6 | 55.0 | 9.70 | 0.11 | 0.01 | 100.531 | ******* |
| 7 | 0.7 | 21.9 | 50.4 | 104.6 | 55.0 | 9.90 | 0.00 | 0.01 | ******* | ******* |

SECONDARY BOX

| N | W* | P* | T* | P*/T* | W*T^.44 | WP | WS | UP | UM | UUPT | UPT MACH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC | FT/SEC | FT/SEC | |
| 1 | 0.0000 | 0.2280 | 0.9149 | 0.2492 | 0.0000 | 3.7697 | 0.0000 | 214.93 | 71.91 | 72.49 | 0.062 |
| 2 | 0.0779 | 0.1744 | 0.9142 | 0.1907 | 0.0749 | 3.7486 | 0.2921 | 213.57 | 76.52 | 72.03 | 0.062 |
| 3 | 0.1363 | 0.1336 | 0.9144 | 0.1461 | 0.1310 | 3.7868 | 0.5160 | 215.49 | 81.05 | 72.68 | 0.062 |
| 4 | 0.2092 | 0.0787 | 0.9131 | 0.0862 | 0.2010 | 3.7491 | 0.7842 | 213.33 | 84.98 | 71.95 | 0.062 |
| 5 | 0.2613 | 0.0308 | 0.9126 | 0.0337 | 0.2510 | 3.7495 | 0.9798 | 213.21 | 88.33 | 71.91 | 0.062 |
| 6 | 0.3060 | 0.0105 | 0.9121 | 0.0116 | 0.2939 | 3.7545 | 1.1489 | 213.49 | 91.36 | 72.00 | 0.062 |
| 7 | ****** | 0.0000 | 0.9121 | 0.0000 | ****** | 3.7558 | 0.0000 | 213.51 | ****** | 72.01 | 0.062 |

TABLE Ia

TERTIARY BOX

| N | WT# | PT# | TT# | PT#/TT# | WT#TT^.44 | WM | WT | UE |
|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC |
| 1 | ****** | 0.0000 | 0.9149 | 0.0000 | ******* | 3.770 | ******* | ****** |
| 2 | ****** | 0.0000 | 0.9142 | 0.0000 | ******* | 4.041 | ******* | ****** |
| 3 | ****** | 0.0000 | 0.9144 | 0.0000 | ******* | 4.303 | ******* | ****** |
| 4 | ****** | 0.0005 | 0.9131 | 0.0005 | ******* | 4.533 | ******* | ****** |
| 5 | ****** | 0.0005 | 0.9126 | 0.0005 | ******* | 4.729 | ******* | ****** |
| 6 | ****** | 0.0005 | 0.9121 | 0.0005 | ******* | 4.903 | ******* | ****** |
| 7 | ****** | 0.0005 | 0.9121 | 0.0005 | ******* | ****** | ******* | ****** |

MIXING STACK PRESSURE DATA-RUN 7 CURVED SIDE DISTRIBUTION

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| X/S: | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 |
| PMS(INH2O): | 0.250 | 0.470 | 0.980 | 1.750 | 2.590 | 3.010 | 2.400 |
| PMS#: | 0.024 | 0.045 | 0.094 | 0.168 | 0.248 | 0.289 | 0.230 |
| X/S: | 2.00 | 2.25 | 2.50 | 2.75 | | | |
| PMS(INH2O): | 0.410 | -3.750 | -0.370 | 0.050 | | | |
| PMS#: | 0.039 | -0.359 | -0.035 | 0.005 | | | |

MIXING STACK PRESSURE DATA-RUN 7 FLAT SIDE DISTRIBUTION

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| X/S: | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 |
| PMS(INH2O): | 1.280 | 0.440 | 0.530 | 0.900 | 0.950 | 0.760 | -0.280 |
| PMS#: | 0.123 | 0.042 | 0.051 | 0.086 | 0.091 | 0.073 | -0.027 |
| X/S: | 2.00 | 2.25 | 2.50 | 2.75 | | | |
| PMS(INH2O): | -0.180 | 0.110 | 0.300 | 0.180 | | | |
| PMS#: | -0.017 | 0.011 | 0.029 | 0.017 | | | |



TABLE IL

DATA TAKEN ON 28 JANUARY 1981
DATA TAKEN BY D.L.RYAN
2 TERTIARY PORTS OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA:107.51 SQ IN

PRIMARY NOZZLE AREA:9.06 SQ IN AREA RATIO (AM/AP): 2.99

MIXING STACK LENGTH:25.50 IN ORIFICE DIAMETER:6.908 IN

MIXING STACK DIMENSION: 8.5 IN ORIFICE BETA:0.497 IN

MIXING STACK L/S:3.00 AMBIENT PRESSURE:29.92 IN HG

| N | POR | DPOR | TOR | TUPT | TAMB | PU-PA | PA-PS | PA-PT | SECONDARY AREA | TERTIARY AREA |
|---|---|---|---|---|---|---|---|---|---|---|
| RUN | IN OF H2O | | | DEGREES F | | | IN OF H2O | | SQUARE INCHES | SQUARE INCHES |
| 1 | 0.7 | 21.8 | 50.3 | 101.6 | 56.0 | 7.25 | 2.57 | 0.00 | 0.000 | ******* |
| 2 | 0.7 | 21.7 | 50.8 | 102.5 | 56.0 | 7.75 | 1.98 | 0.00 | 6.283 | ******* |
| 3 | 0.7 | 21.8 | 50.6 | 103.7 | 56.0 | 8.35 | 1.54 | 0.00 | 12.566 | ******* |
| 4 | 0.7 | 21.8 | 50.7 | 104.1 | 56.0 | 8.90 | 0.94 | 0.00 | 25.133 | ******* |
| 5 | 0.7 | 21.7 | 50.7 | 104.3 | 56.0 | 9.30 | 0.40 | 0.00 | 50.265 | ******* |
| 6 | 0.7 | 22.0 | 50.9 | 104.5 | 56.0 | 9.60 | 0.14 | 0.00 | 100.531 | ******* |
| 7 | 0.7 | 21.9 | 51.0 | 104.8 | 56.0 | 9.90 | 0.03 | 0.00 | ******* | ******* |

SECONDARY BOX

| N | W* | P* | T* | P*/T* | W*T^.44 | WP | WS | UP | UN | UUPT | UPT MACH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC | FT/SEC | FT/SEC | |
| 1 | 0.0000 | 0.2474 | 0.9188 | 0.2693 | 0.0000 | 3.7596 | 0.0000 | 212.58 | 71.12 | 71.69 | 0.062 |
| 2 | 0.0214 | 0.1916 | 0.9173 | 0.2089 | 0.0784 | 3.7491 | 0.3853 | 212.02 | 76.21 | 71.51 | 0.062 |
| 3 | 0.1433 | 0.1480 | 0.9153 | 0.1617 | 0.1378 | 3.7587 | 0.5385 | 212.79 | 80.49 | 71.76 | 0.062 |
| 4 | 0.2239 | 0.0905 | 0.9147 | 0.0989 | 0.2153 | 3.7582 | 0.8415 | 212.59 | 85.66 | 71.70 | 0.062 |
| 5 | 0.2928 | 0.0388 | 0.9144 | 0.0424 | 0.2815 | 3.7497 | 1.0979 | 211.90 | 89.86 | 71.47 | 0.061 |
| 6 | 0.3441 | 0.0134 | 0.9140 | 0.0147 | 0.3308 | 3.7746 | 1.2990 | 213.25 | 93.78 | 71.92 | 0.062 |
| 7 | ****** | 0.0029 | 0.9135 | 0.0032 | ****** | 3.7657 | 9.3958 | 212.80 | ****** | 71.77 | 0.062 |

TABLE IIa

TERTIARY BOX

| N | WT* | PT* | TT* | PT*/TT* | WT*TT^.44 | WM | WT | UE |
|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC |
| 1 | ****** | 0.0000 | 0.9188 | 0.0000 | ******* | 3.760 | ******* | ****** |
| 2 | ****** | 0.0000 | 0.9173 | 0.0000 | ******* | 4.054 | ******* | ****** |
| 3 | ****** | 0.0000 | 0.9153 | 0.0000 | ******* | 4.297 | ******* | ****** |
| 4 | ****** | 0.0000 | 0.9147 | 0.0000 | ******* | 4.600 | ******* | ****** |
| 5 | ****** | 0.0000 | 0.9144 | 0.0000 | ******* | 4.848 | ******* | ****** |
| 6 | ****** | 0.0000 | 0.9140 | 0.0000 | ******* | 5.074 | ******* | ****** |
| 7 | ****** | 0.0000 | 0.9135 | 0.0000 | ******* | ****** | ******* | ****** |

MIXING STACK PRESSURE DATA: RUN 7 CURVED SIDE DISTRIBUTION

| X/S: | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 |
|---|---|---|---|---|---|---|---|
| PMS(INH2O): | -0.010 | 0.235 | 0.670 | 1.460 | 2.250 | 2.590 | 2.060 |
| PMS*: | -0.001 | 0.023 | 0.064 | 0.140 | 0.216 | 0.249 | 0.198 |
| X/S: | 2.00 | 2.25 | 2.50 | 2.75 | | | |
| PMS(INH2O): | 0.520 | -3.620 | -0.390 | 0.040 | | | |
| PMS*: | 0.050 | -0.348 | -0.037 | 0.004 | | | |

MIXING STACK PRESSURE DATA: RUN 7 FLAT SIDE DISTRIBUTION

| X/S: | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 |
|---|---|---|---|---|---|---|---|
| PMS(INH2O): | 1.040 | 0.220 | 0.240 | 0.550 | 0.640 | 0.610 | 0.010 |
| PMS*: | 0.100 | 0.021 | 0.023 | 0.053 | 0.061 | 0.059 | 0.001 |
| X/S: | 2.00 | 2.25 | 2.50 | 2.75 | | | |
| PMS(INH2O): | -0.060 | 0.180 | 0.330 | 0.180 | | | |
| PMS*: | -0.006 | 0.017 | 0.032 | 0.017 | | | |



TABLE IIb

VERTICAL VELOCITY TRAVERSE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| POSIT(IN): | 0.00 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 |
| P(IN H2O): | 1.84 | 2.70 | 2.55 | 2.30 | 2.22 | 2.15 | 2.16 |
| V(FT/SEC): | 89.47 | 108.38 | 105.33 | 100.03 | 98.28 | 96.71 | 96.94 |
| POSIT(IN): | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 | 6.00 | 6.50 |
| P(IN H2O): | 2.15 | 2.17 | 2.18 | 2.17 | 2.16 | 2.18 | 2.25 |
| V(FT/SEC): | 96.71 | 97.16 | 97.39 | 97.16 | 96.94 | 97.39 | 98.94 |
| POSIT(IN): | 7.00 | 7.50 | 8.00 | 8.50 | | | |
| P(IN H2O): | 2.41 | 2.58 | 2.82 | 1.45 | | | |
| V(FT/SEC): | 102.40 | 105.95 | 110.76 | 79.43 | | | |

HORIZONTAL VELOCITY TRAVERSE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| POSIT(IN): | 0.00 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 |
| P(IN H2O): | 0.28 | 2.22 | 2.26 | 2.22 | 2.22 | 2.18 | 2.16 |
| V(FT/SEC): | 34.90 | 98.28 | 99.16 | 98.28 | 98.28 | 97.39 | 96.94 |
| POSIT(IN): | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 | 6.00 | 6.25 |
| P(IN H2O): | 2.13 | 2.16 | 2.17 | 2.18 | 2.22 | 2.19 | 2.18 |
| V(FT/SEC): | 96.26 | 96.94 | 97.16 | 97.39 | 98.28 | 97.61 | 97.39 |
| POSIT(IN): | 6.50 | 6.75 | 7.00 | 7.25 | 7.75 | 8.25 | 8.75 |
| P(IN H2O): | 2.17 | 2.16 | 2.16 | 2.17 | 2.17 | 2.17 | 2.16 |
| V(FT/SEC): | 97.16 | 96.94 | 96.94 | 97.16 | 97.16 | 97.16 | 96.94 |
| POSIT(IN): | 9.25 | 9.75 | 10.25 | 10.75 | 11.25 | 11.75 | 12.25 |
| P(IN H2O): | 2.17 | 2.22 | 2.25 | 2.25 | 2.21 | 2.11 | 2.03 |
| V(FT/SEC): | 97.16 | 98.28 | 98.94 | 98.94 | 98.06 | 95.81 | 93.98 |
| POSIT(IN): | 12.75 | | | | | | |
| P(IN H2O): | 1.55 | | | | | | |
| V(FT/SEC): | 82.12 | | | | | | |

DIAGONAL VELOCITY TRAVERSE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| POSIT(IN): | 0.00 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 |
| P(IN H2O): | 0.52 | 1.84 | 2.88 | 2.89 | 2.69 | 2.48 | 2.34 |
| V(FT/SEC): | 47.56 | 89.47 | 111.94 | 112.13 | 108.18 | 103.87 | 100.90 |
| POSIT(IN): | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 | 6.00 | 6.50 |
| P(IN H2O): | 2.15 | 2.06 | 2.01 | 2.05 | 2.13 | 2.18 | 2.20 |
| V(FT/SEC): | 96.71 | 94.67 | 93.51 | 94.44 | 96.26 | 97.39 | 97.83 |
| POSIT(IN): | 7.00 | 7.50 | 8.00 | 8.50 | 9.00 | 9.50 | 10.00 |
| P(IN H2O): | 2.21 | 2.21 | 2.15 | 2.16 | 2.18 | 2.12 | 2.08 |
| V(FT/SEC): | 98.06 | 98.06 | 96.71 | 96.94 | 97.39 | 96.04 | 95.13 |
| POSIT(IN): | 10.50 | 11.00 | 11.50 | 12.00 | 12.50 | 13.00 | 13.50 |
| P(IN H2O): | 2.05 | 2.03 | 2.03 | 2.05 | 2.16 | 2.28 | 2.38 |
| V(FT/SEC): | 94.44 | 93.98 | 93.98 | 94.44 | 96.94 | 99.60 | 101.76 |
| POSIT(IN): | 14.00 | 14.50 | 15.00 | | | | |
| P(IN H2O): | 2.52 | 2.43 | 1.45 | | | | |
| V(FT/SEC): | 104.71 | 102.82 | 79.43 | | | | |

TABLE IIo

DATA TAKEN ON 28 JANUARY 1981
DATA TAKEN BY D.L.RYAN
1 TERTIARY PORT OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA:107.51 SQ IN

PRIMARY NOZZLE AREA:9.06 SQ IN AREA RATIO (AM/AP): 2.99

MIXING STACK LENGTH:25.50 IN ORIFICE DIAMETER:6.908 IN

MIXING STACK DIMENSION: 8.5 IN ORIFICE BETA:0.497 IN

MIXING STACK L/S:3.00 AMBIENT PRESSURE:29.94 IN HG

| N | POR | DPOR | TOR | TUPT | TAMB | PU-PA | PA-PS | PA-PT | SECONDARY AREA | TERTIARY AREA |
|---|---|---|---|---|---|---|---|---|---|---|
| RUN | IN OF H2O | | | DEGREES F | | IN OF H2O | | | SQUARE INCHES | SQUARE INCHES |
| 1 | 0.7 | 21.8 | 50.7 | 105.0 | 65.0 | 7.10 | 2.73 | 0.00 | 0.000 | ******* |
| 2 | 0.7 | 21.8 | 50.2 | 104.9 | 65.0 | 7.70 | 2.13 | 0.00 | 6.283 | ******* |
| 3 | 0.7 | 21.9 | 50.1 | 104.9 | 65.0 | 8.15 | 1.65 | 0.00 | 12.566 | ******* |
| 4 | 0.7 | 21.8 | 50.3 | 104.9 | 65.0 | 8.75 | 1.03 | 0.00 | 25.133 | ******* |
| 5 | 0.7 | 22.0 | 50.1 | 104.7 | 65.0 | 9.45 | 0.50 | 0.00 | 50.265 | ******* |
| 6 | 0.7 | 21.8 | 50.4 | 104.7 | 65.0 | 9.75 | 0.18 | 0.00 | 100.531 | ******* |
| 7 | 0.9 | 21.8 | 49.8 | 104.7 | 65.0 | 9.85 | 0.03 | 0.00 | ******* | ******* |

SECONDARY BOX

| N | W# | P# | T# | P#/T# | W#T^.44 | WP | WS | UP | UM | UUPT | UPT MACH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC | FT/SEC | FT/SEC | |
| 1 | 0.0000 | 0.2642 | 0.9292 | 0.2843 | 0.0000 | 3.7594 | 0.0000 | 213.80 | 71.53 | 72.10 | 0.062 |
| 2 | 0.0835 | 0.2066 | 0.9293 | 0.2223 | 0.0808 | 3.7612 | 0.3141 | 213.55 | 76.96 | 72.02 | 0.062 |
| 3 | 0.1466 | 0.1597 | 0.9293 | 0.1718 | 0.1420 | 3.7702 | 0.5528 | 213.80 | 81.24 | 72.11 | 0.062 |
| 4 | 0.2323 | 0.1005 | 0.9293 | 0.1081 | 0.2249 | 3.7608 | 0.8736 | 212.95 | 86.59 | 71.82 | 0.062 |
| 5 | 0.3221 | 0.0485 | 0.9297 | 0.0521 | 0.3120 | 3.7787 | 1.2173 | 213.61 | 92.84 | 72.04 | 0.062 |
| 6 | 0.3885 | 0.0176 | 0.9297 | 0.0190 | 0.3762 | 3.7605 | 1.4608 | 212.41 | 96.72 | 71.64 | 0.062 |
| 7 | ****** | 0.0029 | 0.9297 | 0.0032 | ****** | 3.7620 | 9.3180 | 212.41 | ****** | 71.64 | 0.062 |

TABLE IIIa

TERTIARY BOX

| N | WT# | PT# | TT# | PT#/TT# | WT#TT^.44 | WM | WT | UE |
|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC |
| 1 | ****** | 0.0000 | 0.9292 | 0.0000 | ******* | 3.759 | ******* | ****** |
| 2 | ****** | 0.0000 | 0.9293 | 0.0000 | ******* | 4.075 | ******* | ****** |
| 3 | ****** | 0.0000 | 0.9293 | 0.0000 | ******* | 4.323 | ******* | ****** |
| 4 | ****** | 0.0000 | 0.9293 | 0.0000 | ******* | 4.634 | ******* | ****** |
| 5 | ****** | 0.0000 | 0.9297 | 0.0000 | ******* | 4.996 | ******* | ****** |
| 6 | ****** | 0.0000 | 0.9297 | 0.0000 | ******* | 5.221 | ******* | ****** |
| 7 | ****** | 0.0000 | 0.9297 | 0.0000 | ******* | ****** | ******* | ****** |

MIXING STACK PRESSURE DATA: RUN 7 CURVED SIDE DISTRIBUTION

| X/S: | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 |
|---|---|---|---|---|---|---|---|
| PMS(INH2O): | -0.260 | -0.050 | 0.380 | 1.180 | 1.910 | 2.210 | 1.880 |
| PMS#: | -0.025 | -0.005 | 0.037 | 0.116 | 0.187 | 0.217 | 0.184 |
| X/S: | 2.00 | 2.25 | 2.50 | 2.75 | | | |
| PMS(INH2O): | 0.650 | -3.420 | -0.390 | 0.050 | | | |
| PMS#: | 0.064 | -0.335 | -0.038 | 0.005 | | | |

MIXING STACK PRESSURE DATA: RUN 7 FLAT SIDE DISTRIBUTION

| X/S: | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 |
|---|---|---|---|---|---|---|---|
| PMS(INH2O): | 0.780 | -0.090 | -0.080 | 0.070 | 0.090 | 0.330 | 0.200 |
| PMS#: | 0.076 | -0.009 | -0.008 | 0.007 | 0.009 | 0.032 | 0.020 |
| X/S: | 2.00 | 2.25 | 2.50 | 2.75 | | | |
| PMS(INH2O): | 0.080 | 0.240 | 0.360 | 0.230 | | | |
| PMS#: | 0.008 | 0.024 | 0.035 | 0.023 | | | |



TABLE IIIb

VERTICAL VELOCITY TRAVERSE

| POSIT(IN) | 0.00 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 |
|---|---|---|---|---|---|---|---|
| P(IN H2O) | 0.81 | 2.84 | 2.83 | 2.68 | 2.52 | 2.45 | 2.42 |
| V(FT/SEC) | 59.86 | 112.08 | 111.89 | 108.88 | 105.58 | 104.10 | 103.46 |
| POSIT(IN) | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 | 6.00 | 6.50 |
| P(IN H2O) | 2.41 | 2.44 | 2.46 | 2.45 | 2.44 | 2.43 | 2.46 |
| V(FT/SEC) | 103.25 | 103.89 | 104.32 | 104.10 | 103.89 | 103.68 | 104.32 |
| POSIT(IN) | 7.00 | 7.50 | 8.00 | 8.50 | | | |
| P(IN H2O) | 2.51 | 2.59 | 2.76 | 0.90 | | | |
| V(FT/SEC) | 105.37 | 107.04 | 110.49 | 63.10 | | | |

HORIZONTAL VELOCITY TRAVERSE

| POSIT(IN) | 0.00 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 |
|---|---|---|---|---|---|---|---|
| P(IN H2O) | 0.48 | 2.48 | 2.52 | 2.46 | 2.46 | 2.44 | 2.46 |
| V(FT/SEC) | 46.08 | 104.74 | 105.58 | 104.32 | 104.32 | 103.89 | 104.32 |
| POSIT(IN) | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 | 6.00 | 6.25 |
| P(IN H2O) | 2.48 | 2.47 | 2.43 | 2.40 | 2.41 | 2.41 | 2.43 |
| V(FT/SEC) | 104.74 | 104.53 | 103.68 | 103.04 | 103.25 | 103.25 | 103.68 |
| POSIT(IN) | 6.50 | 6.75 | 7.00 | 7.25 | 7.75 | 8.25 | 8.75 |
| P(IN H2O) | 2.42 | 2.43 | 2.45 | 2.44 | 2.46 | 2.47 | 2.45 |
| V(FT/SEC) | 103.46 | 103.68 | 104.10 | 103.89 | 104.32 | 104.53 | 104.10 |
| POSIT(IN) | 9.25 | 9.75 | 10.25 | 10.75 | 11.25 | 11.75 | 12.25 |
| P(IN H2O) | 2.48 | 2.47 | 2.44 | 2.43 | 2.35 | 2.30 | 2.26 |
| V(FT/SEC) | 104.74 | 104.53 | 103.89 | 103.68 | 101.96 | 100.87 | 100.43 |
| POSIT(IN) | 12.75 | | | | | | |
| P(IN H2O) | 1.91 | | | | | | |
| V(FT/SEC) | 91.92 | | | | | | |

DIAGONAL VELOCITY TRAVERSE

| POSIT(IN) | 0.00 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 |
|---|---|---|---|---|---|---|---|
| P(IN H2O) | 0.85 | 2.85 | 2.97 | 3.05 | 3.04 | 2.83 | 2.65 |
| V(FT/SEC) | 61.32 | 112.28 | 114.62 | 116.15 | 115.96 | 111.89 | 108.27 |
| POSIT(IN) | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 | 6.00 | 6.50 |
| P(IN H2O) | 2.52 | 2.42 | 2.38 | 2.38 | 2.43 | 2.46 | 2.50 |
| V(FT/SEC) | 105.58 | 103.46 | 102.61 | 102.61 | 103.68 | 104.32 | 105.16 |
| POSIT(IN) | 7.00 | 7.50 | 8.00 | 8.50 | 9.00 | 9.50 | 10.00 |
| P(IN H2O) | 2.54 | 2.56 | 2.56 | 2.56 | 2.55 | 2.52 | 2.48 |
| V(FT/SEC) | 106.00 | 106.42 | 106.42 | 106.42 | 106.21 | 105.53 | 104.74 |
| POSIT(IN) | 10.50 | 11.00 | 11.50 | 12.00 | 12.50 | 13.00 | 13.50 |
| P(IN H2O) | 2.46 | 2.44 | 2.42 | 2.41 | 2.43 | 2.46 | 2.57 |
| V(FT/SEC) | 104.32 | 103.89 | 103.46 | 103.25 | 103.68 | 104.32 | 106.62 |
| POSIT(IN) | 14.00 | 14.50 | 15.00 | | | | |
| P(IN H2O) | 2.66 | 2.62 | 1.32 | | | | |
| V(FT/SEC) | 108.47 | 107.66 | 82.00 | | | | |

TABLE IIIa

DATA TAKEN ON 1 FEBRUARY 1981
DATA TAKEN BY D.L.RYAN
1 TERTIARY PORT OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA:107.51 SQ IN

PRIMARY NOZZLE AREA:9.06 SQ IN AREA RATIO (AM/AP): 2.99

MIXING STACK LENGTH:25.50 IN ORIFICE DIAMETER:6.908 IN

MIXING STACK DIMENSION: 8.5 IN ORIFICE BETA:0.497 IN

MIXING STACK L/S:3.00 AMBIENT PRESSURE:30.34 IN HG

| N | POR | DPOR | TOR | TUPT | TAMB | PU-PA | PA-PS | PA-PT | SECONDARY AREA | TERTIARY AREA |
|---|---|---|---|---|---|---|---|---|---|---|
| RUN | IN OF H2O | | | DEGREES F | | | IN OF H2O | | SQUARE INCHES | SQUARE INCHES |
| 1 | 0.7 | 21.9 | 43.5 | 93.9 | 54.0 | 6.90 | 2.76 | 0.50 | 0.000 | 0.000 |
| 2 | 0.7 | 21.9 | 43.4 | 95.3 | 54.0 | 7.20 | 2.76 | 0.11 | 0.000 | 6.283 |
| 3 | 0.7 | 21.9 | 43.2 | 96.0 | 54.0 | 7.20 | 2.77 | 0.03 | 0.000 | 12.566 |
| 4 | 0.7 | 21.9 | 43.4 | 96.8 | 54.0 | 7.20 | 2.77 | 0.01 | 0.000 | 25.133 |
| 5 | 0.7 | 21.9 | 42.9 | 97.0 | 54.0 | 7.20 | 2.77 | 0.01 | 0.000 | 37.699 |
| 6 | 0.7 | 21.9 | 43.3 | 97.0 | 54.0 | 7.20 | 2.80 | 0.01 | 0.000 | 100.531 |
| 7 | 0.7 | 21.9 | 43.4 | 96.8 | 54.0 | 7.20 | 2.78 | 0.00 | 0.000 | ******* |

SECONDARY BOX

| N | W* | P* | T* | P*/T* | W*T^.44 | WP | WS | UP | UM | UUPT | UPT MACH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC | FT/SEC | FT/SEC | |
| 1 | 0.0000 | 0.2670 | 0.9279 | 0.2878 | 0.0000 | 3.8203 | 0.0000 | 210.18 | 70.32 | 70.88 | 0.061 |
| 2 | 0.0000 | 0.2656 | 0.9256 | 0.2870 | 0.0000 | 3.8207 | 0.0000 | 210.73 | 70.50 | 71.07 | 0.062 |
| 3 | 0.0000 | 0.2658 | 0.9244 | 0.2875 | 0.0000 | 3.8214 | 0.0000 | 211.04 | 70.61 | 71.18 | 0.062 |
| 4 | 0.0000 | 0.2651 | 0.9231 | 0.2872 | 0.0000 | 3.8207 | 0.0000 | 211.31 | 70.70 | 71.26 | 0.062 |
| 5 | 0.0000 | 0.2647 | 0.9228 | 0.2868 | 0.0000 | 3.8226 | 0.0000 | 211.49 | 70.76 | 71.33 | 0.062 |
| 6 | 0.0000 | 0.2677 | 0.9228 | 0.2901 | 0.0000 | 3.8211 | 0.0000 | 211.42 | 70.73 | 71.30 | 0.062 |
| 7 | 0.0000 | 0.2661 | 0.9231 | 0.2882 | 0.0000 | 3.8207 | 0.0000 | 211.31 | 70.70 | 71.27 | 0.062 |

TABLE IVa

TERTIARY BOX

| N | WT* | PT* | TT* | PT*/TT* | WT*TT^.44 | WM | WT | UE |
|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC |
| 1 | 0.0000 | 0.0484 | 0.9279 | 0.0521 | 0.0000 | 3.820 | 0.000 | 70.32 |
| 2 | 0.0190 | 0.0106 | 0.9256 | 0.0114 | 0.0184 | 3.821 | 0.073 | 71.84 |
| 3 | 0.0198 | 0.0029 | 0.9244 | 0.0031 | 0.0192 | 3.821 | 0.076 | 72.01 |
| 4 | 0.0229 | 0.0010 | 0.9231 | 0.0010 | 0.0221 | 3.821 | 0.088 | 72.32 |
| 5 | 0.0344 | 0.0010 | 0.9228 | 0.0010 | 0.0332 | 3.823 | 0.131 | 73.19 |
| 6 | 0.0648 | 0.0005 | 0.9228 | 0.0005 | 0.0626 | 3.821 | 0.248 | 75.32 |
| 7 | ******* | 0.0000 | 0.9231 | 0.0000 | ******** | 3.821 | ******** | ******* |

MIXING STACK PPESSURE DATA: RUN 7 CURVED SIDE DISTRIBUTION

| X/S: | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 |
|---|---|---|---|---|---|---|---|
| PMS(INH2O): | -1.370 | -0.760 | -0.130 | 0.560 | 1.330 | 1.820 | 1.730 |
| PMS*: | -0.131 | -0.073 | -0.012 | 0.054 | 0.127 | 0.174 | 0.166 |
| X/S: | 2.00 | 2.25 | 2.50 | 2.75 | | | |
| PMS(INH2O): | 0.650 | -1.900 | -0.140 | 0.040 | | | |
| PMS*: | 0.062 | -0.132 | -0.013 | 0.004 | | | |

MIXING STACK PPESSURE DATA: RUN 7 FLAT SIDE DISTRIBUTION

| X/S: | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 |
|---|---|---|---|---|---|---|---|
| PMS(INH2O): | -0.260 | -0.810 | -0.480 | -0.040 | 0.280 | 0.520 | 0.210 |
| PMS*: | -0.025 | -0.078 | -0.046 | -0.004 | 0.027 | 0.050 | 0.020 |
| X/S: | 2.00 | 2.25 | 2.50 | 2.75 | | | |
| PMS(INH2O): | 0.140 | 0.130 | 0.230 | 0.150 | | | |
| PMS*: | 0.013 | 0.012 | 0.022 | 0.014 | | | |



TABLE IVb

VERTICAL VELOCITY TRAVERSE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| POSIT(IN): | 0.00 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 |
| P(IN H2O): | 0.81 | 1.49 | 1.46 | 1.39 | 1.32 | 1.32 | 1.32 |
| V(FT/SEC): | 58.84 | 79.80 | 78.99 | 77.07 | 75.11 | 75.11 | 75.11 |
| POSIT(IN): | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 | 6.00 | 6.50 |
| P(IN H2O): | 1.35 | 1.36 | 1.36 | 1.35 | 1.33 | 1.31 | 1.31 |
| V(FT/SEC): | 75.96 | 76.24 | 76.24 | 75.96 | 75.39 | 74.82 | 74.82 |
| POSIT(IN): | 7.00 | 7.50 | 8.00 | 8.50 | | | |
| P(IN H2O): | 1.38 | 1.35 | 1.48 | 0.49 | | | |
| V(FT/SEC): | 74.54 | 75.96 | 79.53 | 45.76 | | | |

HORIZONTAL VELOCITY TRAVERSE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| POSIT(IN): | 0.00 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 |
| P(IN H2O): | 0.61 | 1.32 | 1.26 | 1.23 | 1.22 | 1.25 | 1.27 |
| V(FT/SEC): | 51.06 | 75.11 | 73.38 | 72.50 | 72.21 | 73.09 | 73.67 |
| POSIT(IN): | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 | 6.00 | 6.25 |
| P(IN H2O): | 1.30 | 1.32 | 1.34 | 1.34 | 1.35 | 1.34 | 1.34 |
| V(FT/SEC): | 74.54 | 75.11 | 75.68 | 75.68 | 75.96 | 75.68 | 75.68 |
| POSIT(IN): | 6.50 | 6.75 | 7.00 | 7.25 | 7.75 | 8.25 | 8.75 |
| P(IN H2O): | 1.35 | 1.34 | 1.36 | 1.36 | 1.38 | 1.39 | 1.43 |
| V(FT/SEC): | 75.96 | 75.68 | 76.24 | 76.24 | 76.80 | 77.07 | 78.18 |
| POSIT(IN): | 9.25 | 9.75 | 10.25 | 10.75 | 11.25 | 11.75 | 12.25 |
| P(IN H2O): | 1.42 | 1.43 | 1.41 | 1.38 | 1.35 | 1.34 | 1.38 |
| V(FT/SEC): | 77.90 | 78.18 | 77.63 | 76.80 | 75.96 | 75.68 | 76.80 |
| POSIT(IN): | 12.75 | | | | | | |
| P(IN H2O): | 1.10 | | | | | | |
| V(FT/SEC): | 68.56 | | | | | | |

DIAGONAL VELOCITY TRAVERSE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| POSIT(IN): | 0.00 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 |
| P(IN H2O): | 0.33 | 1.83 | 1.83 | 1.72 | 1.62 | 1.50 | 1.43 |
| V(FT/SEC): | 37.55 | 88.44 | 88.44 | 85.74 | 83.21 | 80.07 | 78.18 |
| POSIT(IN): | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 | 6.00 | 6.50 |
| P(IN H2O): | 1.33 | 1.30 | 1.33 | 1.35 | 1.35 | 1.35 | 1.36 |
| V(FT/SEC): | 75.39 | 74.54 | 75.39 | 75.96 | 75.96 | 75.96 | 76.24 |
| POSIT(IN): | 7.00 | 7.50 | 8.00 | 8.50 | 9.00 | 9.50 | 10.00 |
| P(IN H2O): | 1.37 | 1.36 | 1.35 | 1.35 | 1.36 | 1.34 | 1.34 |
| V(FT/SEC): | 76.52 | 76.24 | 75.96 | 75.96 | 76.24 | 75.68 | 75.68 |
| POSIT(IN): | 10.50 | 11.00 | 11.50 | 12.00 | 12.50 | 13.00 | 13.50 |
| P(IN H2O): | 1.33 | 1.30 | 1.29 | 1.25 | 1.22 | 1.23 | 1.27 |
| V(FT/SEC): | 75.39 | 74.54 | 74.25 | 73.09 | 72.21 | 72.50 | 73.67 |
| POSIT(IN): | 14.00 | 14.50 | 15.00 | | | | |
| P(IN H2O): | 1.35 | 1.44 | 0.90 | | | | |
| V(FT/SEC): | 75.96 | 78.45 | 62.02 | | | | |

TABLE IVc

DATA TAKEN ON 1 FEBRUARY 1981
DATA TAKEN BY D.L.RYAN
1 TERTIARY PORT OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA:107.51 SQ IN

PRIMARY NOZZLE AREA:9.06 SQ IN AREA RATIO (AM/AP): 2.99

MIXING STACK LENGTH:25.50 IN ORIFICE DIAMETER:6.908 IN

MIXING STACK DIMENSION: 8.5 IN ORIFICE BETA:0.497 IN

MIXING STACK L/S:3.00 AMBIENT PRESSURE:30.35 IN HG

| N | POR | OPOR | TOR | TUPT | TAMB | PU-PA | PA-PS | PA-PT | SECONDARY AREA | TERTIARY AREA |
|---|---|---|---|---|---|---|---|---|---|---|
| RUN | IN OF H2O | | DEGREES F | | | IN OF H2O | | | SQUARE INCHES | SQUARE INCHES |
| 1 | 0.7 | 21.9 | 42.9 | 97.4 | 58.0 | 9.25 | 0.57 | 0.58 | 37.699 | 0.000 |
| 2 | 0.7 | 21.9 | 43.4 | 97.3 | 58.0 | 9.25 | 0.53 | 0.14 | 37.699 | 6.283 |
| 3 | 0.7 | 21.9 | 43.7 | 97.4 | 58.0 | 9.30 | 0.51 | 0.05 | 37.699 | 12.566 |
| 4 | 0.7 | 21.9 | 43.3 | 97.6 | 58.0 | 9.30 | 0.51 | 0.02 | 37.699 | 25.133 |
| 5 | 0.7 | 21.9 | 42.8 | 97.4 | 58.0 | 9.35 | 0.48 | 0.01 | 37.699 | 37.699 |
| 6 | 0.7 | 21.9 | 43.2 | 97.5 | 58.0 | 9.30 | 0.48 | 0.00 | 37.699 | 100.531 |
| 7 | 0.7 | 21.9 | 42.0 | 97.4 | 58.0 | 9.30 | 0.47 | 0.00 | 37.699 | ******* |

SECONDARY BOX

| N | W* | P* | T* | P*/T* | W*T^.44 | WP | WS | UP | UM | UUPT | UPT MACH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC | FT/SEC | FT/SEC | |
| 1 | 0.2584 | 0.0554 | 0.9293 | 0.0596 | 0.2502 | 3.8232 | 0.9881 | 210.47 | 87.31 | 70.98 | 0.061 |
| 2 | 0.2493 | 0.0516 | 0.9294 | 0.0555 | 0.2414 | 3.8213 | 0.9528 | 210.31 | 86.65 | 70.93 | 0.061 |
| 3 | 0.2446 | 0.0497 | 0.9293 | 0.0534 | 0.2369 | 3.8202 | 0.9346 | 210.28 | 86.33 | 70.92 | 0.061 |
| 4 | 0.2446 | 0.0496 | 0.9289 | 0.0534 | 0.2367 | 3.8217 | 0.9346 | 210.44 | 86.38 | 70.97 | 0.061 |
| 5 | 0.2371 | 0.0467 | 0.9293 | 0.0502 | 0.2296 | 3.8236 | 0.9067 | 210.45 | 85.91 | 70.98 | 0.061 |
| 6 | 0.2372 | 0.0467 | 0.9291 | 0.0502 | 0.2297 | 3.8221 | 0.9067 | 210.40 | 85.89 | 70.96 | 0.061 |
| 7 | 0.2345 | 0.0456 | 0.9293 | 0.0491 | 0.2270 | 3.8267 | 0.8972 | 210.61 | 85.88 | 71.03 | 0.061 |

TABLE Va

TERTIARY BOX

| N | WT# | PT# | TT# | PT#/TT# | WT#TT^.44 | WM | WT | UE |
|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC |
| 1 | 0.0000 | 0.0564 | 0.9293 | 0.0607 | 0.0000 | 4.811 | 0.000 | 87.31 |
| 2 | 0.0214 | 0.0136 | 0.9294 | 0.0147 | 0.0207 | 4.774 | 0.082 | 88.13 |
| 3 | 0.0255 | 0.0049 | 0.9293 | 0.0052 | 0.0247 | 4.755 | 0.098 | 88.10 |
| 4 | 0.0323 | 0.0019 | 0.9289 | 0.0021 | 0.0313 | 4.756 | 0.123 | 88.62 |
| 5 | 0.0342 | 0.0010 | 0.9293 | 0.0010 | 0.0331 | 4.730 | 0.131 | 88.28 |
| 6 | 0.0000 | 0.0000 | 0.9291 | 0.0000 | 0.0000 | 4.729 | 0.000 | 85.89 |
| 7 | ****** | 0.0000 | 0.9293 | 0.0000 | ******* | 4.724 | ******* | ****** |

MIXING STACK PRESSURE DATA: RUN 7 CURVED SIDE DISTRIBUTION

| X/S: | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 |
|---|---|---|---|---|---|---|---|
| PMS(INH2O): | -0.520 | -0.230 | 0.200 | 0.930 | 1.760 | 2.090 | 1.920 |
| PMS#: | -0.050 | -0.022 | 0.019 | 0.090 | 0.171 | 0.203 | 0.186 |
| X/S: | 2.00 | 2.25 | 2.50 | 2.75 | | | |
| PMS(INH2O): | 0.840 | -3.050 | -0.260 | 0.060 | | | |
| PMS#: | 0.082 | -0.296 | -0.025 | 0.006 | | | |

MIXING STACK PRESSURE DATA: RUN 7 FLAT SIDE DISTRIBUTION

| X/S: | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 |
|---|---|---|---|---|---|---|---|
| PMS(INH2O): | 0.780 | -0.220 | -0.240 | 0.030 | 0.230 | 0.400 | 0.110 |
| PMS#: | 0.076 | -0.021 | -0.023 | 0.003 | 0.022 | 0.039 | 0.011 |
| X/S: | 2.00 | 2.25 | 2.50 | 2.75 | | | |
| PMS(INH2O): | 0.150 | 0.300 | 0.450 | 0.270 | | | |
| PMS#: | 0.015 | 0.029 | 0.044 | 0.026 | | | |



TABLE Vb

DATA TAKEN ON 2 FEBRUARY 1981
DATA TAKEN BY D.L.RYAN
1 TERTIARY PORT OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA:107.51 SQ IN

PRIMARY NOZZLE AREA:9.06 SQ IN AREA RATIO (AM/AP): 2.99

MIXING STACK LENGTH:25.50 IN ORIFICE DIAMETER:6.908 IN

MIXING STACK DIMENSION: 8.5 IN ORIFICE BETA:0.497 IN

MIXING STACK L/S:3.00 AMBIENT PRESSURE:30.27 IN HG

| N | POR | DPOR | TOR | TUPT | TAMB | PU-PA | PA-PS | PA-PT | SECONDARY AREA | TERTIARY AREA |
|---|---|---|---|---|---|---|---|---|---|---|
| RUN | IN OF H2O | | DEGREES | | F | IN OF H2O | | | SQUARE INCHES | SQUARE INCHES |
| 1 | 0.7 | 21.9 | 50.3 | 104.2 | 66.0 | 9.85 | 0.01 | 0.62 | ******* | 0.000 |
| 2 | 0.7 | 22.0 | 52.0 | 104.5 | 66.0 | 9.85 | 0.01 | 0.13 | ******* | 6.283 |
| 3 | 0.7 | 22.1 | 51.5 | 104.6 | 66.0 | 9.90 | 0.01 | 0.04 | ******* | 12.566 |
| 4 | 0.7 | 22.1 | 50.8 | 104.8 | 66.0 | 9.90 | 0.01 | 0.02 | ******* | 25.133 |
| 5 | 0.7 | 21.8 | 52.5 | 105.2 | 66.0 | 9.80 | 0.01 | 0.01 | ******* | 50.265 |
| 6 | 0.7 | 21.8 | 50.2 | 105.0 | 66.0 | 9.80 | 0.01 | 0.00 | ******* | 100.531 |
| 7 | 0.7 | 21.8 | 51.7 | 105.1 | 66.0 | 9.80 | 0.00 | 0.00 | ******* | ******* |

SECONDARY BOX

| N | W# | P# | T# | P#/T# | W#T^.44 | WP | WS | UP | UM | UUPT | UPT MACH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC | FT/SEC | FT/SEC | |
| 1 | ****** | 0.0005 | 0.9323 | 0.0005 | ****** | 3.7903 | 3.8213 | 211.48 | ****** | 71.32 | 0.061 |
| 2 | ****** | 0.0005 | 0.9318 | 0.0005 | ****** | 3.7927 | 3.8213 | 211.72 | ****** | 71.41 | 0.061 |
| 3 | ****** | 0.0005 | 0.9316 | 0.0005 | ****** | 3.8031 | 3.8213 | 212.35 | ****** | 71.62 | 0.062 |
| 4 | ****** | 0.0005 | 0.9313 | 0.0005 | ****** | 3.8057 | 3.8213 | 212.57 | ****** | 71.69 | 0.062 |
| 5 | ****** | 0.0005 | 0.9306 | 0.0005 | ****** | 3.7736 | 3.8213 | 210.92 | ****** | 71.13 | 0.061 |
| 6 | ****** | 0.0005 | 0.9309 | 0.0005 | ****** | 3.7821 | 3.8213 | 211.32 | ****** | 71.27 | 0.061 |
| 7 | ****** | 0.0000 | 0.9308 | 0.0000 | ****** | 3.7765 | 0.0000 | 211.04 | ****** | 71.18 | 0.061 |

TABLE VIa

TERTIARY BOX

| N | WT# | PT# | TT# | PT#/TT# | WT#TT^.44 | WM | WT | UE |
|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC |
| 1 | 0.0000 | 0.0608 | 0.9323 | 0.0652 | 0.0000 | ****** | 0.000 | ****** |
| 2 | 0.0206 | 0.0127 | 0.9318 | 0.0136 | 0.0199 | ****** | 0.078 | ****** |
| 3 | 0.0227 | 0.0039 | 0.9316 | 0.0042 | 0.0220 | ****** | 0.086 | ****** |
| 4 | 0.0278 | 0.0015 | 0.9313 | 0.0016 | 0.0270 | ****** | 0.106 | ****** |
| 5 | 0.0324 | 0.0005 | 0.9306 | 0.0005 | 0.0314 | ****** | 0.122 | ****** |
| 6 | 0.0000 | 0.0000 | 0.9309 | 0.0000 | 0.0000 | ****** | 0.000 | ****** |
| 7 | ****** | 0.0000 | 0.9308 | 0.0000 | ******* | ****** | ******* | ****** |

MIXING STACK PRESSURE DATA: RUN 7 CURVED SIDE DISTRIBUTION

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| X/S: | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 |
| PMS(INH2O): | -0.240 | -0.030 | 0.400 | 1.080 | 1.950 | 2.230 | 1.790 |
| PMS#: | -0.024 | -0.003 | 0.039 | 0.106 | 0.192 | 0.219 | 0.176 |
| X/S: | 2.00 | 2.25 | 2.50 | 2.75 | | | |
| PMS(INH2O): | 0.570 | -3.540 | -0.390 | 0.050 | | | |
| PMS#: | 0.056 | -0.348 | -0.038 | 0.005 | | | |

MIXING STACK PRESSURE DATA: RUN 7 FLAT SIDE DISTRIBUTION

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| X/S: | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 |
| PMS(INH2O): | 1.090 | 0.040 | 0.060 | 0.110 | 0.200 | -0.540 | 0.160 |
| PMS#: | 0.107 | 0.004 | 0.006 | 0.011 | 0.020 | -0.053 | 0.016 |
| X/S: | 2.00 | 2.25 | 2.50 | 2.75 | | | |
| PMS(INH2O): | 0.210 | 0.260 | 0.350 | 0.260 | | | |
| PMS#: | 0.021 | 0.026 | 0.034 | 0.026 | | | |



TABLE VIb

DATA TAKEN ON 2 FEBRUARY 1981
DATA TAKEN BY D.L.RYAN
*2 TERTIARY PORTS OPEN/CUSP IN*

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA:107.51 SQ IN

PRIMARY NOZZLE AREA:9.06 SQ IN AREA RATIO (AM/AP): 2.99

MIXING STACK LENGTH:25.50 IN ORIFICE DIAMETER:6.908 IN

MIXING STACK DIMENSION: 8.5 IN ORIFICE BETA:0.497 IN

MIXING STACK L/S:3.00 AMBIENT PRESSURE:30.26 IN HG

| N | POR | DPOR | TOR | TUPT | TAMB | PU-PA | PA-PS | PA-PT | SECONDARY AREA | TERTIARY AREA |
|---|---|---|---|---|---|---|---|---|---|---|
| RUN | IN OF H2O | | DEGREES F | | | IN OF H2O | | | SQUARE INCHES | SQUARE INCHES |
| 1 | 0.7 | 21.9 | 43.5 | 97.3 | 58.0 | 7.20 | 2.78 | 1.00 | 0.000 | 0.000 |
| 2 | 0.7 | 21.9 | 42.6 | 96.9 | 58.0 | 7.35 | 2.63 | 0.26 | 0.000 | 6.283 |
| 3 | 0.7 | 21.9 | 42.5 | 96.6 | 58.0 | 7.40 | 2.60 | 0.10 | 0.000 | 12.566 |
| 4 | 0.7 | 21.9 | 43.1 | 96.7 | 58.0 | 7.40 | 2.57 | 0.03 | 0.000 | 25.133 |
| 5 | 0.7 | 21.9 | 42.6 | 96.9 | 58.0 | 7.40 | 2.57 | 0.01 | 0.000 | 50.265 |
| 6 | 0.7 | 21.9 | 42.9 | 96.9 | 58.0 | 7.40 | 2.56 | 0.00 | 0.000 | 100.531 |
| 7 | 0.7 | 21.9 | 42.9 | 96.8 | 58.0 | 7.40 | 2.56 | 0.00 | 0.000 | ******* |

SECONDARY BOX

| N | W1 | P* | T* | P*/T* | W*T^.44 | WP | WS | UP | UH | UUPT | UPT MACH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC | FT/SEC | FT/SEC | |
| 1 | 0.0000 | 0.2677 | 0.9294 | 0.2880 | 0.0000 | 3.8152 | 0.0000 | 211.76 | 70.85 | 71.42 | 0.062 |
| 2 | 0.0000 | 0.2534 | 0.9301 | 0.2724 | 0.0000 | 3.8187 | 0.0000 | 211.72 | 70.84 | 71.41 | 0.062 |
| 3 | 0.0000 | 0.2507 | 0.9306 | 0.2694 | 0.0000 | 3.8191 | 0.0000 | 211.62 | 70.80 | 71.37 | 0.062 |
| 4 | 0.0000 | 0.2481 | 0.9304 | 0.2666 | 0.0000 | 3.8168 | 0.0000 | 211.51 | 70.76 | 71.33 | 0.062 |
| 5 | 0.0000 | 0.2477 | 0.9301 | 0.2663 | 0.0000 | 3.8187 | 0.0000 | 211.69 | 70.83 | 71.39 | 0.062 |
| 6 | 0.0000 | 0.2468 | 0.9301 | 0.2654 | 0.0000 | 3.8175 | 0.0000 | 211.62 | 70.80 | 71.37 | 0.062 |
| 7 | 0.0000 | 0.2469 | 0.9303 | 0.2654 | 0.0000 | 3.8175 | 0.0000 | 211.59 | 70.79 | 71.36 | 0.062 |

TABLE VIIa

TERTIARY BOX

| N | WT$ | PT$ | TT$ | PT$/TT$ | WT$TT^.44 | WM | WT | UE |
|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC |
| 1 | 0.0000 | 0.0963 | 0.9294 | 0.1036 | 0.0000 | 3.815 | 0.000 | 70.85 |
| 2 | 0.0291 | 0.0250 | 0.9301 | 0.0269 | 0.0282 | 3.819 | 0.111 | 72.90 |
| 3 | 0.0361 | 0.0096 | 0.9306 | 0.0104 | 0.0349 | 3.819 | 0.138 | 73.35 |
| 4 | 0.0395 | 0.0029 | 0.9304 | 0.0031 | 0.0383 | 3.817 | 0.151 | 73.56 |
| 5 | 0.0323 | 0.0005 | 0.9301 | 0.0005 | 0.0313 | 3.819 | 0.123 | 73.11 |
| 6 | 0.0000 | 0.0000 | 0.9301 | 0.0000 | 0.0000 | 3.818 | 0.000 | 70.00 |
| 7 | ****** | 0.0000 | 0.9303 | 0.0000 | ******* | 3.818 | ******* | ****** |



TABLE VIIb

DATA TAKEN ON 2 FEBRUARY 1981
DATA TAKEN BY D.L.RYAN
2 TERTIARY PORTS OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA:107.51 SQ IN

PRIMARY NOZZLE AREA:9.06 SQ IN AREA RATIO (AM/AP): 2.99

MIXING STACK LENGTH:25.50 IN ORIFICE DIAMETER:6.900 IN

MIXING STACK DIMENSION: 8.5 IN ORIFICE BETA:0.497 IN

MIXING STACK L/S:3.00 AMBIENT PRESSURE:30.24 IN HG

| N | POR | DPOR | TOR | TUPT | TAMB | PU-PA | PA-PS | PA-PT | SECONDARY AREA | TERTIARY AREA |
|---|---|---|---|---|---|---|---|---|---|---|
| RUN | IN OF H2O | | | DEGREES F | | | IN OF H2O | | SQUARE INCHES | SQUARE INCHES |
| 1 | 0.7 | 22.1 | 43.0 | 96.9 | 57.0 | 9.00 | 1.04 | 1.08 | 37.699 | 0.000 |
| 2 | 0.7 | 22.1 | 43.4 | 97.5 | 57.0 | 9.10 | 0.90 | 0.27 | 37.699 | 6.283 |
| 3 | 0.7 | 22.1 | 43.7 | 97.2 | 57.0 | 9.10 | 0.90 | 0.08 | 37.699 | 12.566 |
| 4 | 0.7 | 22.0 | 42.8 | 96.9 | 57.0 | 9.10 | 0.89 | 0.04 | 37.699 | 25.133 |
| 5 | 0.7 | 22.0 | 43.1 | 96.8 | 57.0 | 9.10 | 0.89 | 0.01 | 37.699 | 50.265 |
| 6 | 0.7 | 22.0 | 43.5 | 97.0 | 57.0 | 9.10 | 0.89 | 0.01 | 37.699 | 100.531 |
| 7 | 0.7 | 22.0 | 43.6 | 97.3 | 57.0 | 9.10 | 0.89 | 0.00 | 37.699 | ******* |

SECONDARY BOX

| N | W* | P* | T* | P*/T* | W*T^.44 | WP | WS | UP | UM | UUPT | UPT MACH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC | FT/SEC | FT/SEC | |
| 1 | 0.3479 | 0.0999 | 0.9283 | 0.1077 | 0.3367 | 3.8333 | 1.3335 | 211.85 | 93.71 | 71.45 | 0.062 |
| 2 | 0.3237 | 0.0864 | 0.9273 | 0.0932 | 0.3132 | 3.8318 | 1.2405 | 211.92 | 92.14 | 71.47 | 0.062 |
| 3 | 0.3238 | 0.0866 | 0.9278 | 0.0933 | 0.3133 | 3.8306 | 1.2405 | 211.75 | 92.08 | 71.41 | 0.062 |
| 4 | 0.3225 | 0.0859 | 0.9283 | 0.0926 | 0.3121 | 3.8254 | 1.2336 | 211.34 | 91.83 | 71.27 | 0.062 |
| 5 | 0.3226 | 0.0860 | 0.9285 | 0.0927 | 0.3122 | 3.8242 | 1.2336 | 211.23 | 91.79 | 71.24 | 0.062 |
| 6 | 0.3227 | 0.0860 | 0.9281 | 0.0927 | 0.3123 | 3.8227 | 1.2336 | 211.23 | 91.79 | 71.24 | 0.062 |
| 7 | 0.3227 | 0.0860 | 0.9276 | 0.0927 | 0.3122 | 3.8223 | 1.2336 | 211.32 | 91.82 | 71.27 | 0.062 |

TABLE VIIIa

TERTIARY BOX

| N | WT% | PT% | TT% | PT%/TT% | WT%TT^.44 | WM | WT | UE |
|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC |
| 1 | 0.0000 | 0.0961 | 0.9283 | 0.1035 | 0.0000 | 5.167 | 0.000 | 93.71 |
| 2 | 0.0296 | 0.0259 | 0.9273 | 0.0280 | 0.0286 | 5.072 | 0.113 | 94.20 |
| 3 | 0.0322 | 0.0077 | 0.9278 | 0.0083 | 0.0311 | 5.071 | 0.123 | 94.32 |
| 4 | 0.0456 | 0.0039 | 0.9283 | 0.0042 | 0.0441 | 5.059 | 0.174 | 94.99 |
| 5 | 0.0456 | 0.0010 | 0.9285 | 0.0010 | 0.0441 | 5.058 | 0.174 | 94.96 |
| 6 | 0.0645 | 0.0005 | 0.9281 | 0.0005 | 0.0624 | 5.056 | 0.247 | 96.27 |
| 7 | ****** | 0.0000 | 0.9276 | 0.0000 | ******* | 5.056 | ******* | ****** |



TABLE VIIIb

DATA TAKEN ON 2 FEBRUARY 1981
DATA TAKEN BY D.L.RYAN
2 TERTIARY PORTS OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA:107.51 SQ IN

PRIMARY NOZZLE AREA:9.06 SQ IN AREA RATIO (AM/AP): 2.99

MIXING STACK LENGTH:25.50 IN ORIFICE DIAMETER:6.908 IN

MIXING STACK DIMENSION: 8.5 IN ORIFICE BETA:0.497 IN

MIXING STACK L/S:3.00 AMBIENT PRESSURE:30.24 IN HG

| N | POR | DPOR | TOR | TUPT | TAMB | PU-PA | PA-PS | PA-PT | SECONDARY AREA | TERTIARY AREA |
|---|---|---|---|---|---|---|---|---|---|---|
| RUN | IN OF H2O | | DEGREES F | | | IN OF H2O | | | SQUARE INCHES | SQUARE INCHES |
| 1 | 0.7 | 21.8 | 43.5 | 94.7 | 55.0 | 9.85 | 0.01 | 1.20 | ******* | 0.000 |
| 2 | 0.7 | 21.8 | 43.6 | 96.2 | 55.0 | 9.80 | 0.01 | 0.25 | ******* | 6.283 |
| 3 | 0.7 | 21.8 | 43.9 | 96.8 | 55.0 | 9.85 | 0.01 | 0.11 | ******* | 12.566 |
| 4 | 0.7 | 21.8 | 43.3 | 96.6 | 55.0 | 9.85 | 0.01 | 0.03 | ******* | 25.133 |
| 5 | 0.7 | 21.9 | 43.5 | 96.9 | 55.0 | 9.85 | 0.01 | 0.01 | ******* | 50.265 |
| 6 | 0.7 | 21.8 | 43.8 | 97.0 | 55.0 | 9.85 | 0.01 | 0.00 | ******* | 100.531 |
| 7 | 0.7 | 21.9 | 43.7 | 97.2 | 55.0 | 9.85 | 0.00 | 0.00 | ******* | ******* |

SECONDARY BOX

| N | W* | P* | T* | P*/T* | W*T^.44 | WP | WS | UP | UM | UUPT | UFT MACH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC | FT/SEC | FT/SEC | |
| 1 | 0.3372 | 0.0942 | 0.9298 | 0.1013 | 0.3265 | 3.8165 | 1.2868 | 210.89 | 92.62 | 71.13 | 0.061 |
| 2 | 0.3060 | 0.0777 | 0.9298 | 0.0836 | 0.2964 | 3.8184 | 1.1686 | 210.91 | 90.60 | 71.13 | 0.062 |
| 3 | 0.3003 | 0.0748 | 0.9299 | 0.0805 | 0.2908 | 3.8181 | 1.1465 | 210.84 | 90.20 | 71.11 | 0.061 |
| 4 | 0.2964 | 0.0730 | 0.9303 | 0.0785 | 0.2872 | 3.8169 | 1.1315 | 210.69 | 89.89 | 71.06 | 0.061 |
| 5 | 0.2961 | 0.0728 | 0.9303 | 0.0783 | 0.2868 | 3.8218 | 1.1315 | 210.96 | 89.98 | 71.15 | 0.062 |
| 6 | 0.2958 | 0.0727 | 0.9303 | 0.0781 | 0.2865 | 3.8252 | 1.1315 | 211.15 | 90.05 | 71.21 | 0.062 |
| 7 | 0.2938 | 0.0717 | 0.9304 | 0.0771 | 0.2846 | 3.8256 | 1.1239 | 211.13 | 89.91 | 71.20 | 0.062 |

TABLE IXa

TERTIARY BOX

| N | WT$ | PT$ | TT$ | PT$/TT$ | WT$TT^.44 | WM | WT | UE |
|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC |
| 1 | 0.0000 | 0.1389 | 0.9298 | 0.1494 | 0.0000 | 5.103 | 0.000 | 92.62 |
| 2 | 0.0361 | 0.0388 | 0.9298 | 0.0418 | 0.0349 | 4.987 | 0.138 | 93.11 |
| 3 | 0.0470 | 0.0165 | 0.9299 | 0.0178 | 0.0456 | 4.965 | 0.180 | 93.46 |
| 4 | 0.0510 | 0.0049 | 0.9303 | 0.0052 | 0.0494 | 4.948 | 0.195 | 93.43 |
| 5 | 0.0456 | 0.0010 | 0.9303 | 0.0010 | 0.0442 | 4.953 | 0.174 | 93.15 |
| 6 | 0.0000 | 0.0000 | 0.9303 | 0.0000 | 0.0000 | 4.957 | 0.000 | 90.05 |
| 7 | ****** | 0.0000 | 0.9304 | 0.0000 | ******* | 4.950 | ******* | ****** |



TABLE IXb

DATA TAKEN ON 2 FEBRUARY 1981
DATA TAKEN BY D.L.RYAN
3 TERTIARY PORTS OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA:107.51 SQ IN

PRIMARY NOZZLE AREA:9.06 SQ IN AREA RATIO (AM/AP): 2.99

MIXING STACK LENGTH:25.50 IN ORIFICE DIAMETER:6.908 IN

MIXING STACK DIMENSION: 8.5 IN ORIFICE BETA:0.497 IN

MIXING STACK L/S:3.00 AMBIENT PRESSURE:30.24 IN HG

| N | POR | DPOR | TOR | TUPT | TAMB | PU-PA | PA-PS | PA-PT | SECONDARY AREA | TERTIARY AREA |
|---|---|---|---|---|---|---|---|---|---|---|
| RUN | IN OF H20. | | DEGREES F | | | IN OF H20 | | | SQUARE INCHES | SQUARE INCHES |
| 1 | 0.7 | 21.9 | 42.3 | 96.7 | 58.0 | 7.25 | 2.77 | 1.34 | 0.000 | 0.000 |
| 2 | 0.7 | 21.9 | 41.9 | 96.5 | 58.0 | 7.45 | 2.50 | 0.36 | 0.000 | 6.283 |
| 3 | 0.7 | 21.9 | 42.8 | 96.6 | 58.0 | 7.50 | 2.44 | 0.16 | 0.000 | 12.566 |
| 4 | 0.7 | 21.9 | 43.0 | 96.7 | 58.0 | 7.50 | 2.40 | 0.05 | 0.000 | 25.133 |
| 5 | 0.7 | 21.9 | 43.2 | 96.8 | 58.0 | 7.55 | 2.40 | 0.01 | 0.000 | 50.265 |
| 6 | 0.7 | 21.9 | 42.6 | 96.7 | 58.0 | 7.50 | 2.40 | 0.00 | 0.000 | 100.531 |
| 7 | 0.7 | 21.9 | 42.9 | 96.8 | 58.0 | 7.50 | 2.38 | 0.00 | 0.000 | ******* |

SECONDARY BOX

| N | W# | P# | T# | P#/T# | W#T^.44 | WP | WS | UP | UM | UUPT | UPT MACH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC | FT/SEC | FT/SEC | |
| 1 | 0.0000 | 0.2667 | 0.9304 | 0.2866 | 0.0000 | 3.8186 | 0.0000 | 211.65 | 70.88 | 71.45 | 0.062 |
| 2 | 0.0000 | 0.2410 | 0.9308 | 0.2589 | 0.0000 | 3.8201 | 0.0000 | 211.72 | 70.84 | 71.41 | 0.062 |
| 3 | 0.0000 | 0.2356 | 0.9306 | 0.2532 | 0.0000 | 3.8167 | 0.0000 | 211.54 | 70.77 | 71.34 | 0.062 |
| 4 | 0.0000 | 0.2318 | 0.9304 | 0.2491 | 0.0000 | 3.8159 | 0.0000 | 211.52 | 70.77 | 71.34 | 0.062 |
| 5 | 0.0000 | 0.2318 | 0.9303 | 0.2492 | 0.0000 | 3.8151 | 0.0000 | 211.51 | 70.76 | 71.33 | 0.062 |
| 6 | 0.0000 | 0.2316 | 0.9304 | 0.2489 | 0.0000 | 3.8174 | 0.0000 | 211.60 | 70.79 | 71.36 | 0.062 |
| 7 | 0.0000 | 0.2298 | 0.9303 | 0.2470 | 0.0000 | 3.8163 | 0.0000 | 211.56 | 70.78 | 71.35 | 0.062 |

TABLE Xa

TERTIARY BOX

| N | MT# | PT# | TT# | PT#/TT# | MT#TT^.44 | WM | WT | UE |
|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC |
| 1 | 0.0000 | 0.1290 | 0.9304 | 0.1387 | 0.0000 | 3.819 | 0.000 | 70.88 |
| 2 | 0.0342 | 0.0347 | 0.9308 | 0.0373 | 0.0331 | 3.820 | 0.131 | 73.26 |
| 3 | 0.0456 | 0.0155 | 0.9306 | 0.0166 | 0.0442 | 3.817 | 0.174 | 74.00 |
| 4 | 0.0510 | 0.0048 | 0.9304 | 0.0052 | 0.0494 | 3.816 | 0.195 | 74.38 |
| 5 | 0.0323 | 0.0005 | 0.9303 | 0.0005 | 0.0313 | 3.815 | 0.123 | 73.05 |
| 6 | 0.0000 | 0.0000 | 0.9304 | 0.0000 | 0.0000 | 3.817 | 0.000 | 70.79 |
| 7 | ****** | 0.0000 | 0.9303 | 0.0000 | ******* | 3.816 | ******* | ****** |



TABLE XL

DATA TAKEN ON 2 FEBRUARY 1981
DATA TAKEN BY D.L.RYAN
3 TERTIARY PORTS OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA: 107.51 SQ IN

PRIMARY NOZZLE AREA: 9.06 SQ IN AREA RATIO (AM/AP): 2.99

MIXING STACK LENGTH: 25.50 IN ORIFACE DIAMETER: 6.908 IN

MIXING STACK DIMENSION: 8.5 IN ORIFICE BETA: 0.497 IN

MIXING STACK L/S: 3.00 AMBIENT PRESSURE: 30.25 IN HG

| N | POR | DPOR | TOR | TUPT | TAMB | PU-PA | PA-PS | PA-PT | SECONDARY AREA | TERTIARY AREA |
|---|---|---|---|---|---|---|---|---|---|---|
| RUN | IN OF H20 | | DEGREES F | | | IN OF H20 | | | SQUARE INCHES | SQUARE INCHES |
| 1 | 0.7 | 21.9 | 43.0 | 97.1 | 58.0 | 9.00 | 0.97 | 1.43 | 37.699 | 0.000 |
| 2 | 0.7 | 21.9 | 42.5 | 97.1 | 58.0 | 9.15 | 0.80 | 0.40 | 37.699 | 6.283 |
| 3 | 0.7 | 21.9 | 42.6 | 97.0 | 58.0 | 9.15 | 0.77 | 0.17 | 37.699 | 12.566 |
| 4 | 0.7 | 21.9 | 42.9 | 96.8 | 58.0 | 9.20 | 0.75 | 0.05 | 37.699 | 25.133 |
| 5 | 0.7 | 22.0 | 43.9 | 96.8 | 58.0 | 9.20 | 0.75 | 0.01 | 37.699 | 50.265 |
| 6 | 0.7 | 22.0 | 43.0 | 96.8 | 58.0 | 9.15 | 0.75 | 0.00 | 37.699 | 100.531 |
| 7 | 0.7 | 22.0 | 42.9 | 96.7 | 58.0 | 9.20 | 0.74 | 0.00 | 37.699 | ******* |

SECONDARY BOX

| N | W* | P* | T* | P*/T* | W*T^.44 | WP | WS | UP | UM | UUPT | UPT MACH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC | FT/SEC | FT/SEC | |
| 1 | 0.3372 | 0.0942 | 0.9298 | 0.1013 | 0.3265 | 3.8165 | 1.2868 | 210.89 | 92.62 | 71.13 | 0.061 |
| 2 | 0.3060 | 0.0777 | 0.9298 | 0.0836 | 0.2964 | 3.8184 | 1.1686 | 210.91 | 90.60 | 71.13 | 0.062 |
| 3 | 0.3003 | 0.0748 | 0.9299 | 0.0805 | 0.2908 | 3.8181 | 1.1465 | 210.84 | 90.20 | 71.11 | 0.061 |
| 4 | 0.2964 | 0.0730 | 0.9303 | 0.0785 | 0.2872 | 3.8169 | 1.1315 | 210.69 | 89.89 | 71.06 | 0.061 |
| 5 | 0.2961 | 0.0728 | 0.9303 | 0.0783 | 0.2868 | 3.8218 | 1.1315 | 210.96 | 89.98 | 71.15 | 0.062 |
| 6 | 0.2958 | 0.0727 | 0.9303 | 0.0781 | 0.2865 | 3.8252 | 1.1315 | 211.15 | 90.05 | 71.21 | 0.062 |
| 7 | 0.2938 | 0.0717 | 0.9304 | 0.0771 | 0.2846 | 3.8256 | 1.1239 | 211.13 | 89.91 | 71.20 | 0.062 |

TABLE XIa

TERTIARY BOX

| N | WT* | PT* | TT* | PT*/TT* | WT*TT^.44 | WM | MT | UE |
|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC |
| 1 | 0.0000 | 0.1389 | 0.9298 | 0.1494 | 0.0000 | 5.103 | 0.000 | 92.62 |
| 2 | 0.0361 | 0.0388 | 0.9298 | 0.0418 | 0.0349 | 4.987 | 0.138 | 93.11 |
| 3 | 0.0470 | 0.0165 | 0.9299 | 0.0178 | 0.0456 | 4.965 | 0.180 | 93.46 |
| 4 | 0.0510 | 0.0049 | 0.9303 | 0.0052 | 0.0494 | 4.948 | 0.195 | 93.43 |
| 5 | 0.0456 | 0.0010 | 0.9303 | 0.0010 | 0.0442 | 4.953 | 0.174 | 93.15 |
| 6 | 0.0000 | 0.0000 | 0.9303 | 0.0000 | 0.0000 | 4.957 | 0.000 | 90.85 |
| 7 | ****** | 0.0000 | 0.9304 | 0.0000 | ******* | 4.950 | ******* | ****** |



TABLE XIb

DATA TAKEN ON 2 FEBRUARY 1981
DATA TAKEN BY D.L.RYAN
3 TERTIARY PORTS OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA: 107.51 SQ IN

PRIMARY NOZZLE AREA: 9.06 SQ IN AREA RATIO (AM/AP): 2.99

MIXING STACK LENGTH: 25.50 IN ORIFICE DIAMETER: 6.908 IN

MIXING STACK DIMENSION: 8.5 IN ORIFICE BETA: 0.497 IN

MIXING STACK L/S: 3.00 AMBIENT PRESSURE: 30.25 IN HG

| N | POR | DPOR | TOR | TUPT | TAMB | PU-PA | PA-PS | PA-PT | SECONDARY AREA | TERTIARY AREA |
|---|---|---|---|---|---|---|---|---|---|---|
| RUN | IN OF H2O | | | DEGREES F | | | IN OF H2O | | SQUARE INCHES | SQUARE INCHES |
| 1 | 0.7 | 21.9 | 42.7 | 97.0 | 58.0 | 9.80 | 0.00 | 1.59 | ******* | 0.000 |
| 2 | 0.7 | 21.9 | 42.4 | 96.7 | 58.0 | 9.85 | 0.00 | 0.35 | ******* | 6.283 |
| 3 | 0.7 | 21.9 | 42.8 | 96.9 | 58.0 | 9.85 | 0.00 | 0.15 | ******* | 12.566 |
| 4 | 0.7 | 21.9 | 42.6 | 96.8 | 58.0 | 9.90 | 0.00 | 0.05 | ******* | 25.133 |
| 5 | 0.7 | 21.9 | 42.7 | 96.5 | 58.0 | 9.90 | 0.00 | 0.01 | ******* | 50.265 |
| 6 | 0.7 | 21.9 | 42.2 | 96.5 | 58.0 | 9.90 | 0.00 | 0.00 | ******* | 100.531 |
| 7 | 0.7 | 21.9 | 42.0 | 96.5 | 58.0 | 9.90 | 0.00 | 0.00 | ******* | ******* |

SECONDARY BOX

| N | W* | P* | T* | P*/T* | W*T^.44 | WP | WS | UP | UM | UUPT | UPT MACH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC | FT/SEC | FT/SEC | |
| 1 | ****** | 0.0000 | 0.9299 | 0.0000 | ****** | 3.8177 | 0.0000 | 210.42 | ****** | 70.97 | 0.061 |
| 2 | ****** | 0.0000 | 0.9304 | 0.0000 | ****** | 3.8188 | 0.0000 | 210.37 | ****** | 70.95 | 0.061 |
| 3 | ****** | 0.0000 | 0.9301 | 0.0000 | ****** | 3.8173 | 0.0000 | 210.36 | ****** | 70.95 | 0.061 |
| 4 | ****** | 0.0000 | 0.9303 | 0.0000 | ****** | 3.8181 | 0.0000 | 210.37 | ****** | 70.95 | 0.061 |
| 5 | ****** | 0.0000 | 0.9308 | 0.0000 | ****** | 3.8177 | 0.0000 | 210.23 | ****** | 70.90 | 0.061 |
| 6 | ****** | 0.0000 | 0.9308 | 0.0000 | ****** | 3.8196 | 0.0000 | 210.34 | ****** | 70.94 | 0.061 |
| 7 | ****** | 0.0000 | 0.9308 | 0.0000 | ****** | 3.8203 | 0.0000 | 210.38 | ****** | 70.95 | 0.061 |

TABLE XIIa

TERTIARY BOX

| N | WT# | PT# | TT# | PT#/TT# | WT#TT^.44 | WM | WT | UE |
|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC |
| 1 | 0.0000 | 0.1551 | 0.9299 | 0.1668 | 0.0000 | ****** | 0.000 | ****** |
| 2 | 0.0337 | 0.0342 | 0.9304 | 0.0367 | 0.0327 | ****** | 0.129 | ****** |
| 3 | 0.0434 | 0.0142 | 0.9301 | 0.0152 | 0.0421 | ****** | 0.166 | ****** |
| 4 | 0.0484 | 0.0044 | 0.9303 | 0.0047 | 0.0469 | ****** | 0.185 | ****** |
| 5 | 0.0323 | 0.0005 | 0.9308 | 0.0005 | 0.0313 | ****** | 0.123 | ****** |
| 6 | 0.0000 | 0.0000 | 0.9308 | 0.0000 | 0.0000 | ****** | 0.000 | ****** |
| 7 | ****** | 0.0000 | 0.9308 | 0.0000 | ******* | ****** | ******* | ****** |



TABLE XIIb

DATA TAKEN ON 9 MARCH 1981
DATA TAKEN BY D.L.RYAN
2 TERTIARY PORTS OPEN/SIDE MOD

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA:107.51 SQ IN

PRIMARY NOZZLE AREA:9.86 SQ IN AREA RATIO (AM/AP): 2.99

MIXING STACK LENGTH:25.50 IN ORIFICE DIAMETER:6.900 IN

MIXING STACK DIMENSION: 8.5 IN ORIFICE BETA:0.497 IN

MIXING STACK L/S:3.00 AMBIENT PRESSURE:30.23 IN HG

| N | POR | OPOR | TOR | TUPT | TAMB | PU-PA | PA-PS | PA-PT | SECONDARY AREA | TERTIARY AREA |
|---|---|---|---|---|---|---|---|---|---|---|
| RUN | IN OF H2O | | DEGREES F | | | IN OF H2O | | | SQUARE INCHES | SQUARE INCHES |
| 1 | 0.7 | 22.0 | 58.9 | 113.2 | 83.0 | 7.00 | 2.17 | 0.00 | 6.283 | ******* |
| 2 | 0.7 | 22.0 | 57.6 | 112.6 | 83.0 | 9.10 | 0.86 | 0.00 | 25.133 | ******* |
| 3 | 0.7 | 22.0 | 59.6 | 113.0 | 83.0 | 9.70 | 0.15 | 0.00 | 100.531 | ******* |

SECONDARY BOX

| N | W# | P# | T# | P#/T# | W#T^.44 | WP | WS | UP | UM | UUPT | UPT MACH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC | FT/SEC | FT/SEC | |
| 1 | 0.0832 | 0.2130 | 0.9473 | 0.2249 | 0.0812 | 3.7652 | 0.3132 | 214.64 | 77.51 | 72.46 | 0.062 |
| 2 | 0.2092 | 0.0850 | 0.9483 | 0.0896 | 0.2044 | 3.7695 | 0.7887 | 214.18 | 85.85 | 72.23 | 0.062 |
| 3 | 0.3502 | 0.0149 | 0.9476 | 0.0157 | 0.3420 | 3.7623 | 1.3175 | 213.55 | 95.15 | 72.02 | 0.061 |

TABLE XIIIa

TERTIARY BOX

| N | WT# | PT# | TT# | PT#/TT# | WT#TT^.44 | WM | WT | UE |
|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC |
| 1 | ****** | 0.0000 | 0.9473 | 0.0000 | ******* | 4.078 | ******* | ****** |
| 2 | ****** | 0.0000 | 0.9483 | 0.0000 | ******* | 4.558 | ******* | ****** |
| 3 | ****** | 0.0000 | 0.9476 | 0.0000 | ******* | 5.080 | ******* | ****** |

MIXING STACK PRESSURE DATA: RUN 3 CURVED SIDE DISTRIBUTION

| X/S: | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 |
|---|---|---|---|---|---|---|---|
| PMS(INH2O): | -0.040 | 0.210 | 0.640 | 1.440 | 2.320 | 2.720 | 2.010 |
| PMS#: | -0.004 | 0.021 | 0.064 | 0.143 | 0.231 | 0.270 | 0.200 |
| X/S: | 2.00 | 2.25 | 2.50 | 2.75 | | | |
| PMS(INH2O): | 0.040 | -0.980 | -0.740 | -0.710 | | | |
| PMS#: | 0.004 | -0.097 | -0.074 | -0.071 | | | |

MIXING STACK PPESSURE DATA: RUN 3 FLAT SIDE DISTRIBUTION

| X/S: | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 |
|---|---|---|---|---|---|---|---|
| PMS(INH2O): | 0.710 | 0.390 | 0.320 | 0.570 | 0.640 | 0.580 | -0.320 |
| PMS#: | 0.071 | 0.039 | 0.032 | 0.057 | 0.064 | 0.058 | -0.032 |
| X/S: | 2.00 | 2.25 | 2.50 | 2.75 | | | |
| PMS(INH2O): | -0.130 | 0.320 | 0.450 | 0.250 | | | |
| PMS#: | -0.013 | 0.032 | 0.045 | 0.025 | | | |



TABLE XIIIb

VERTICAL VELOCITY TRAVERSE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| POSIT(IN): | 0.00 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 |
| P(IN H2O): | 1.16 | 2.85 | 2.54 | 2.19 | 2.05 | 1.93 | 1.92 |
| V(FT/SEC): | 72.50 | 113.64 | 107.28 | 99.62 | 96.38 | 93.52 | 93.28 |
| POSIT(IN): | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 | 6.00 | 6.50 |
| P(IN H2O): | 1.96 | 2.03 | 2.12 | 2.19 | 2.28 | 2.40 | 2.52 |
| V(FT/SEC): | 94.24 | 95.91 | 98.01 | 99.62 | 101.64 | 104.29 | 106.86 |
| POSIT(IN): | 7.00 | 7.50 | 8.00 | 8.50 | | | |
| P(IN H2O): | 2.67 | 2.74 | 2.31 | 1.72 | | | |
| V(FT/SEC): | 110.08 | 111.43 | 102.31 | 88.28 | | | |

HORIZONTAL VELOCITY TRAVERSE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| POSIT(IN): | 0.00 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 |
| P(IN H2O): | 0.94 | 2.12 | 2.08 | 2.01 | 1.95 | 1.80 | 1.72 |
| V(FT/SEC): | 65.27 | 98.01 | 97.08 | 95.44 | 94.00 | 90.31 | 88.28 |
| POSIT(IN): | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 | 6.00 | 6.25 |
| P(IN H2O): | 1.71 | 1.75 | 1.83 | 1.92 | 2.05 | 2.10 | 2.13 |
| V(FT/SEC): | 88.03 | 89.05 | 91.06 | 93.28 | 96.38 | 97.55 | 98.24 |
| POSIT(IN): | 6.50 | 6.75 | 7.00 | 7.25 | 7.75 | 8.25 | 8.75 |
| P(IN H2O): | 2.13 | 2.12 | 2.12 | 2.13 | 2.10 | 2.09 | 2.06 |
| V(FT/SEC): | 98.24 | 98.01 | 98.01 | 98.24 | 97.55 | 97.32 | 96.62 |
| POSIT(IN): | 9.25 | 9.75 | 10.25 | 10.75 | 11.25 | 11.75 | 12.25 |
| P(IN H2O): | 2.08 | 2.11 | 2.11 | 2.04 | 2.02 | 2.03 | 2.07 |
| V(FT/SEC): | 97.08 | 97.78 | 97.78 | 96.15 | 95.67 | 95.91 | 96.85 |
| POSIT(IN): | 12.75 | | | | | | |
| P(IN H2O): | 1.43 | | | | | | |
| V(FT/SEC): | 80.50 | | | | | | |

DIAGONAL VELOCITY TRAVERSE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| POSIT(IN): | 0.00 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 |
| P(IN H2O): | 1.76 | 2.64 | 2.83 | 2.85 | 2.55 | 2.32 | 2.15 |
| V(FT/SEC): | 89.30 | 109.38 | 114.24 | 113.64 | 107.49 | 102.53 | 98.70 |
| POSIT(IN): | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 | 6.00 | 6.50 |
| P(IN H2O): | 2.04 | 2.03 | 2.00 | 2.03 | 2.06 | 2.09 | 2.08 |
| V(FT/SEC): | 96.15 | 95.91 | 95.20 | 95.91 | 96.62 | 97.32 | 97.08 |
| POSIT(IN): | 7.00 | 7.50 | 8.00 | 8.50 | 9.00 | 9.50 | 10.00 |
| P(IN H2O): | 2.10 | 2.12 | 2.12 | 2.09 | 2.02 | 1.89 | 1.70 |
| V(FT/SEC): | 97.55 | 98.01 | 98.01 | 97.32 | 95.67 | 92.54 | 87.77 |
| POSIT(IN): | 10.50 | 11.00 | 11.50 | 12.00 | 12.50 | 13.00 | 13.50 |
| P(IN H2O): | 1.73 | 1.80 | 1.95 | 2.18 | 2.51 | 2.82 | 3.08 |
| V(FT/SEC): | 88.54 | 90.31 | 94.00 | 99.39 | 106.65 | 113.04 | 118.14 |
| POSIT(IN): | 14.00 | 14.50 | 15.00 | | | | |
| P(IN H2O): | 2.98 | 2.78 | 0.95 | | | | |
| V(FT/SEC): | 116.21 | 112.24 | 65.61 | | | | |

TABLE XIIIa

DATA TAKEN ON 9 MARCH 1981
DATA TAKEN BY D.L.RYAN
2 TERTIARY PORTS OPEN/SIDE MOD

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA:107.51 SQ IN

PRIMARY NOZZLE AREA:9.06 SQ IN AREA RATIO (AM/AP): 2.99

MIXING STACK LENGTH:25.50 IN ORIFICE DIAMETER:6.900 IN

MIXING STACK DIMENSION: 8.5 IN ORIFICE BETA:0.497 IN

MIXING STACK L/S:3.00 AMBIENT PRESSURE:30.29 IN HG

| N | POR | OPOR | TOR | TUPT | TAMB | PU-PA | PA-PS | PA-PT | SECONDARY AREA | TERTIARY AREA |
|---|---|---|---|---|---|---|---|---|---|---|
| RUN | IN OF H2O | | | DEGREES F | | IN OF H2O | | | SQUARE INCHES | SQUARE INCHES |
| 1 | 0.7 | 22.0 | 47.0 | 100.2 | 57.0 | 7.40 | 2.59 | 0.31 | 0.000 | 6.283 |
| 2 | 0.7 | 22.0 | 48.0 | 101.2 | 57.0 | 7.45 | 2.56 | 0.04 | 0.000 | 25.133 |
| 3 | 0.7 | 22.0 | 47.0 | 101.4 | 57.0 | 7.45 | 2.54 | 0.01 | 0.000 | 100.531 |

SECONDARY BOX

| N | WS | PS | TS | PS/TS | WS*T^.44 | WP | WS | UP | UM | UUPT | UPT MACH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC | FT/SEC | FT/SEC | |
| 1 | 0.0000 | 0.2476 | 0.9228 | 0.2683 | 0.0000 | 3.8096 | 0.0000 | 212.24 | 71.01 | 71.58 | 0.062 |
| 2 | 0.0000 | 0.2440 | 0.9212 | 0.2648 | 0.0000 | 3.8088 | 0.0000 | 212.56 | 71.12 | 71.69 | 0.062 |
| 3 | 0.0000 | 0.2418 | 0.9209 | 0.2626 | 0.0000 | 3.8096 | 0.0000 | 212.67 | 71.15 | 71.72 | 0.062 |

TABLE XIVa

TERTIARY BOX

| N | WT$ | PT$ | TT$ | PT$/TT$ | WT$*TT^.44 | WM | WT | UE |
|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC |
| 1 | 0.0319 | 0.0296 | 0.9228 | 0.0321 | 0.0308 | 3.810 | 0.121 | 73.27 |
| 2 | 0.0458 | 0.0038 | 0.9212 | 0.0041 | 0.0442 | 3.809 | 0.174 | 74.37 |
| 3 | 0.0648 | 0.0005 | 0.9209 | 0.0005 | 0.0625 | 3.810 | 0.247 | 75.76 |



TABLE XIVb

DATA TAKEN ON 9 MARCH 1981
DATA TAKEN BY D.L.RYAN
2 TERTIARY PORTS OPEN/SIDE MOD

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA:107.51 SQ IN

PRIMARY NOZZLE AREA:9.06 SQ IN AREA RATIO (AM/AP): 2.99

MIXING STACK LENGTH:25.50 IN ORIFICE DIAMETER:6.908 IN

MIXING STACK DIMENSION: 8.5 IN ORIFICE BETA:0.497 IN

MIXING STACK L/S:3.00 AMBIENT PRESSURE:30.30 IN HG

| N | POR | DPOR | TOR | TUPT | TAMB | PU-PA | PA-PS | PA-PT | SECONDARY AREA | TERTIARY AREA |
|---|---|---|---|---|---|---|---|---|---|---|
| RUN | IN OF H20 | | DEGREES F | | | IN OF H20 | | | SQUARE INCHES | SQUARE INCHES |
| 1 | 0.7 | 22.0 | 48.4 | 102.2 | 58.0 | 9.48 | 0.57 | 0.28 | 37.699 | 6 283 |
| 2 | 0.7 | 22.0 | 48.8 | 102.2 | 58.0 | 9.48 | 0.57 | 0.04 | 37.699 | 25.133 |
| 3 | 0.7 | 22.0 | 49.0 | 102.2 | 58.0 | 9.48 | 0.57 | 0.01 | 37.699 | 100.531 |

SECONDARY BOX

| N | W# | P# | T# | P#/T# | W#T^.44 | WP | WS | UP | UM | UUPT | UPT MACH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC | FT/SEC | FT/SEC | |
| 1 | 0.2593 | 0.0548 | 0.9213 | 0.0595 | 0.2501 | 3.8080 | 0.9872 | 211.79 | 87.76 | 71.43 | 0.061 |
| 2 | 0.2594 | 0.0548 | 0.9213 | 0.0595 | 0.2502 | 3.8065 | 0.9872 | 211.71 | 87.73 | 71.40 | 0.061 |
| 3 | 0.2594 | 0.0549 | 0.9213 | 0.0596 | 0.2502 | 3.8057 | 0.9872 | 211.67 | 87.72 | 71.39 | 0.061 |

TABLE XVa

TERTIARY BOX

| N | WT% | PT% | TT% | PT%/TT% | WT%TT^.44 | WM | WT | UE |
|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC |
| 1 | 0.0303 | 0.0269 | 0.9213 | 0.0292 | 0.0292 | 4.795 | 0.115 | 89.87 |
| 2 | 0.0458 | 0.0038 | 0.9213 | 0.0042 | 0.0442 | 4.794 | 0.174 | 90.92 |
| 3 | 0.0648 | 0.0005 | 0.9213 | 0.0005 | 0.0625 | 4.793 | 0.247 | 92.23 |



TABLE XVb

DATA TAKEN ON 9 MARCH 1981
DATA TAKEN BY D.L.RYAN
3 TERTIARY PORTS OPEN/SIDE MOD

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA:107.51 SQ IN

PRIMARY NOZZLE AREA:9.06 SQ IN AREA RATIO (AM/AP): 2.99

MIXING STACK LENGTH:25.50 IN ORIFICE DIAMETER:6.908 IN

MIXING STACK DIMENSION: 8.5 IN ORIFICE BETA:0.497 IN

MIXING STACK L/S:3.00 AMBIENT PRESSURE:30.32 IN HG

| N | POR | DPOR | TOR | TUPT | TAMB | PU-PA | PA-PS | PA-PT | SECONDARY AREA | TERTIARY AREA |
|---|---|---|---|---|---|---|---|---|---|---|
| RUN | IN OF H2O | | | DEGREES F | | IN OF H2O | | | SQUARE INCHES | SQUARE INCHES |
| 1 | 0.7 | 21.9 | 53.4 | 107.0 | 68.0 | 8.10 | 1.86 | 0.00 | 6.283 | ******* |
| 2 | 0.7 | 22.0 | 53.2 | 107.2 | 68.0 | 9.20 | 0.81 | 0.00 | 25.133 | ******* |
| 3 | 0.7 | 22.0 | 52.6 | 106.6 | 68.0 | 9.80 | 0.13 | 0.00 | 100.531 | ******* |
| 4 | 0.7 | 21.9 | 53.4 | 107.0 | 68.0 | 9.85 | 0.03 | 0.00 | ******* | ******* |

SECONDARY BOX

| N | W# | P# | T# | P#/T# | W#T^.44 | WP | WS | UP | UN | UUPT | UPT MACH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC | FT/SEC | FT/SEC | |
| 1 | 0.0779 | 0.1807 | 0.9312 | 0.1940 | 0.0755 | 3.7820 | 0.2945 | 212.67 | 76.29 | 71.72 | 0.061 |
| 2 | 0.2050 | 0.0786 | 0.9308 | 0.0845 | 0.1987 | 3.7913 | 0.7774 | 212.73 | 84.73 | 71.74 | 0.061 |
| 3 | 0.3284 | 0.0127 | 0.9318 | 0.0136 | 0.3183 | 3.7936 | 1.2457 | 212.28 | 92.74 | 71.59 | 0.061 |
| 4 | ****** | 0.0029 | 0.9312 | 0.0032 | ****** | 3.7820 | 9.3502 | 211.73 | ****** | 71.41 | 0.061 |

TABLE XVIa

TERTIARY BOX

| N | WT# | PT# | TT# | PT#/TT# | WT#TT^.44 | WM | WT | UE |
|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC |
| 1 | ****** | 0.0000 | 0.9312 | 0.0000 | ******* | 4.076 | ******* | ****** |
| 2 | ****** | 0.0000 | 0.9309 | 0.0000 | ******* | 4.569 | ******* | ****** |
| 3 | ****** | 0.0000 | 0.9318 | 0.0000 | ******* | 5.039 | ******* | ****** |
| 4 | ****** | 0.0000 | 0.9312 | 0.0000 | ******* | ****** | ******* | ****** |

MIXING STACK PRESSURE DATA: RUN 4 CURVED SIDE DISTRIBUTION

| X/S: | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 |
|---|---|---|---|---|---|---|---|
| PHS(INH2O): | 0.030 | 0.400 | 0.850 | 1.570 | 2.440 | 2.910 | 2.140 |
| PHS#: | 0.003 | 0.039 | 0.083 | 0.154 | 0.239 | 0.285 | 0.210 |
| X/S: | 2.00 | 2.25 | 2.50 | 2.75 | | | |
| PHS(INH2O): | -0.020 | -1.250 | -0.870 | -0.740 | | | |
| PHS#: | -0.002 | -0.122 | -0.085 | -0.073 | | | |

MIXING STACK PRESSURE DATA: RUN 4 FLAT SIDE DISTRIBUTION

| X/S: | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 |
|---|---|---|---|---|---|---|---|
| PHS(INH2O): | 0.850 | 0.600 | 0.610 | 0.930 | 1.020 | 0.770 | -0.740 |
| PHS#: | 0.083 | 0.059 | 0.060 | 0.091 | 0.100 | 0.075 | -0.073 |
| X/S: | 2.00 | 2.25 | 2.50 | 2.75 | | | |
| PHS(INH2O): | -0.230 | 0.210 | 0.370 | 0.220 | | | |
| PHS#: | -0.023 | 0.021 | 0.036 | 0.022 | | | |



TABLE XVIb

VERTICAL VELOCITY TRAVERSE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| POSIT(IN): | 0.00 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 |
| P(IN H2O): | 1.57 | 2.77 | 2.35 | 2.07 | 1.92 | 1.84 | 1.85 |
| V(FT/SEC): | 83.05 | 110.31 | 101.61 | 95.36 | 91.84 | 89.91 | 90.15 |
| POSIT(IN): | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 | 6.00 | 6.50 |
| P(IN H2O): | 1.88 | 1.92 | 2.03 | 2.16 | 2.31 | 2.36 | 2.63 |
| V(FT/SEC): | 90.88 | 91.84 | 94.44 | 97.41 | 100.74 | 101.82 | 107.49 |
| POSIT(IN): | 7.00 | 7.50 | 8.00 | 8.50 | | | |
| P(IN H2O): | 2.86 | 2.93 | 2.69 | 0.95 | | | |
| V(FT/SEC): | 112.09 | 113.45 | 108.71 | 64.60 | | | |

HORIZONTAL VELOCITY TRAVERSE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| POSIT(IN): | 0.00 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 |
| P(IN H2O): | 1.85 | 1.85 | 1.80 | 1.86 | 1.85 | 1.63 | 1.81 |
| V(FT/SEC): | 67.92 | 90.15 | 88.92 | 90.39 | 90.15 | 89.66 | 89.17 |
| POSIT(IN): | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 | 6.00 | 6.25 |
| P(IN H2O): | 1.82 | 1.86 | 1.91 | 1.97 | 2.00 | 2.03 | 1.99 |
| V(FT/SEC): | 89.42 | 90.39 | 91.60 | 93.03 | 93.73 | 94.44 | 93.50 |
| POSIT(IN): | 6.50 | 6.75 | 7.00 | 7.25 | 7.75 | 8.25 | 8.75 |
| P(IN H2O): | 2.01 | 1.98 | 2.00 | 1.99 | 1.98 | 1.98 | 1.97 |
| V(FT/SEC): | 93.97 | 93.26 | 93.73 | 93.50 | 93.26 | 93.26 | 93.03 |
| POSIT(IN): | 9.25 | 9.75 | 10.25 | 10.75 | 11.25 | 11.75 | 12.25 |
| P(IN H2O): | 2.01 | 2.03 | 2.07 | 2.04 | 2.01 | 1.96 | 1.84 |
| V(FT/SEC): | 93.97 | 94.44 | 95.36 | 94.67 | 93.97 | 92.79 | 89.91 |
| POSIT(IN): | 12.75 | | | | | | |
| P(IN H2O): | 1.04 | | | | | | |
| V(FT/SEC): | 67.59 | | | | | | |

DIAGONAL VELOCITY TRAVERSE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| POSIT(IN): | 0.00 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 |
| P(IN H2O): | 1.30 | 2.43 | 2.74 | 2.78 | 2.63 | 2.41 | 2.26 |
| V(FT/SEC): | 75.57 | 103.32 | 109.71 | 110.51 | 107.49 | 102.89 | 93.64 |
| POSIT(IN): | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 | 6.00 | 6.50 |
| P(IN H2O): | 2.16 | 2.12 | 2.11 | 2.10 | 2.09 | 2.03 | 1.97 |
| V(FT/SEC): | 97.41 | 96.51 | 96.28 | 96.05 | 95.82 | 94.44 | 93.03 |
| POSIT(IN): | 7.00 | 7.50 | 8.00 | 8.50 | 9.00 | 9.50 | 10.00 |
| P(IN H2O): | 1.93 | 1.94 | 1.94 | 1.99 | 2.00 | 1.98 | 1.95 |
| V(FT/SEC): | 92.08 | 92.32 | 92.32 | 93.50 | 93.73 | 93.26 | 92.56 |
| POSIT(IN): | 10.50 | 11.00 | 11.50 | 12.00 | 12.50 | 13.00 | 13.50 |
| P(IN H2O): | 1.87 | 1.87 | 1.95 | 2.10 | 2.28 | 2.59 | 2.71 |
| V(FT/SEC): | 90.64 | 90.64 | 92.56 | 96.05 | 100.08 | 106.67 | 109.11 |
| POSIT(IN): | 14.00 | 14.50 | 15.00 | | | | |
| P(IN H2O): | 2.47 | 2.30 | 1.98 | | | | |
| V(FT/SEC): | 104.17 | 100.52 | 93.26 | | | | |

TABLE XVIc

DATA TAKEN ON 9 MARCH 1981
DATA TAKEN BY D.L.RYAN
3 TERTIARY PORTS OPEN/SIDE MOD

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA:107.51 SQ IN

PRIMARY NOZZLE AREA:9.06 SQ IN AREA RATIO (AM/AP): 2.99

MIXING STACK LENGTH:25.50 IN ORIFICE DIAMETER:6.908 IN

MIXING STACK DIMENSION: 8.5 IN ORIFICE BETA:0.497 IN

MIXING STACK L/S:3.00 AMBIENT PRESSURE:30.28 IN HG

| N | POR | DPOR | TOR | TUPT | TAMB | PU-PA | PA-PS | PA-PT | SECONDARY AREA | TERTIARY AREA |
|---|---|---|---|---|---|---|---|---|---|---|
| RUN | IN OF H20 | | DEGREES F | | | IN OF H20 | | | SQUARE INCHES | SQUARE INCHES |
| 1 | 0.7 | 22.0 | 49.6 | 99.0 | 56.0 | 7.50 | 2.46 | 0.43 | 0.000 | 6.283 |
| 2 | 0.7 | 22.0 | 49.4 | 100.8 | 56.0 | 7.60 | 2.35 | 0.04 | 0.000 | 25.133 |
| 3 | 0.7 | 22.0 | 49.2 | 101.4 | 56.0 | 7.65 | 2.35 | 0.01 | 0.000 | 100.531 |

SECONDARY BOX

| N | W* | P* | T* | P*/T* | W*T^.44 | WP | WS | UP | UM | UUPT | UPT MACH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC | FT/SEC | FT/SEC | |
| 1 | 0.0000 | 0.2367 | 0.9230 | 0.2564 | 0.0000 | 3.8022 | 0.0000 | 211.38 | 70.72 | 71.29 | 0.062 |
| 2 | 0.0000 | 0.2247 | 0.9201 | 0.2442 | 0.0000 | 3.8030 | 0.0000 | 212.04 | 70.94 | 71.51 | 0.062 |
| 3 | 0.0000 | 0.2241 | 0.9191 | 0.2438 | 0.0000 | 3.8037 | 0.0000 | 212.31 | 71.03 | 71.60 | 0.062 |

TABLE XVIIa

TERTIARY BOX

| N | WT$ | PT$ | TT$ | PT$/TT$ | WT$TT^.44 | WM | WT | UE |
|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC |
| 1 | 0.0376 | 0.0414 | 0.9230 | 0.0448 | 0.0363 | 3.802 | 0.143 | 73.38 |
| 2 | 0.9459 | 0.0038 | 0.9201 | 0.0042 | 0.0443 | 3.803 | 0.175 | 74.20 |
| 3 | 0.0918 | 0.0010 | 0.9191 | 0.0010 | 0.0885 | 3.804 | 0.349 | 77.55 |



TABLE XVIIb

DATA TAKEN ON 9 MARCH 1981
DATA TAKEN BY D.L.RYAN
3 TERTIARY PORTS OPEN/SIDE MOD

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA:107.51 SQ IN

PRIMARY NOZZLE AREA:9.06 SQ IN AREA RATIO (AM/AP): 2.99

MIXING STACK LENGTH:25.50 IN ORIFICE DIAMETER:6.908 IN

MIXING STACK DIMENSION: 8.5 IN ORIFICE BETA:0.497 IN

MIXING STACK L/S:3.00 AMBIENT PRESSURE:30.28 IN HG

| N | POR | DPOR | TOR | TUPT | TAMB | PU-PA | PA-PS | PA-PT | SECONDARY AREA | TERTIARY AREA |
|---|---|---|---|---|---|---|---|---|---|---|
| RUN | IN OF H20 | | DEGREES F | | | IN OF H20 | | | SQUARE INCHES | SQUARE INCHES |
| 1 | 0.7 | 22.0 | 48.6 | 102.0 | 58.0 | 9.50 | 0.53 | 0.40 | 37.699 | 6.283 |
| 2 | 0.7 | 22.0 | 48.4 | 101.6 | 58.0 | 9.50 | 0.48 | 0.07 | 37.699 | 25.133 |
| 3 | 0.7 | 22.0 | 48.4 | 101.8 | 58.0 | 9.50 | 0.46 | 0.01 | 37.699 | 100.531 |

SECONDARY BOX

| N | W# | P# | T# | P#/T# | W#T^.44 | WP | WS | UP | UH | UUPT | UPT MACH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC | FT/SEC | FT/SEC | |
| 1 | 0.2500 | 0.0510 | 0.9217 | 0.0554 | 0.2412 | 3.8060 | 0.9517 | 211.72 | 87.14 | 71.41 | 0.061 |
| 2 | 0.2379 | 0.0463 | 0.9223 | 0.0502 | 0.2296 | 3.8067 | 0.9057 | 211.59 | 86.31 | 71.36 | 0.061 |
| 3 | 0.2329 | 0.0443 | 0.9220 | 0.0481 | 0.2247 | 3.8067 | 0.8866 | 211.65 | 86.00 | 71.38 | 0.061 |

TABLE XVIIIa

TERTIARY BOX

| N | WT# | PT# | TT# | PT#/TT# | WT#TT^.44 | WH | WT | UE |
|---|---|---|---|---|---|---|---|---|
| RUN | | | | | | LBM/SEC | LBM/SEC | FT/SEC |
| 1 | 0.0362 | 0.0385 | 0.9217 | 0.0418 | 0.0349 | 4.750 | 0.138 | 89.66 |
| 2 | 0.0606 | 0.0067 | 0.9223 | 0.0073 | 0.0585 | 4.712 | 0.231 | 90.53 |
| 3 | 0.0916 | 0.0010 | 0.9228 | 0.0010 | 0.0884 | 4.693 | 0.349 | 92.39 |



TABLE XVIIIb

# APPENDIX: A

## ONE-DIMENSIONAL ANALYSIS OF A SIMPLE EDUCTOR

This investigation, being an extension of the work of Shaw [Ref. 8], and others Ref. 1, 2 and 7] uses the same one-dimensional analysis of a simple eductor system. Similarity between the basic geometry tested by previous researchers was maintained in order to correlate data. The demensionless parameters controlling the flow phenomena used previously were also used in this investigation along with the basic means of data analysis and presentation. Dynamic similarity was maintained by using Mach number similarity to establish the model's primary flow rate.

Although the analysis presented here is for an eductor model with only primary and secondary air flows, it should be kept in mind that many of the results presented are for systems with primary, secondary, and tertiary air flows. Systems with tertiary and film or wall cooling air flows have been non-dimensionalized with the same base parameters as the secondary air flow and have been calculated using the same one-dimensional analysis. This allows for easy comparison of the results. Parameters pertaining to the secondary systems are subscripted with an "s", those relating to the tertiary box are subscripted with a "t".

## A. MODELING TECHNIQUE

Dynamic similarity between the models tested and the actual prototype was maintained by using the same primary air flow Mach number. For the primary air flow Mach number used (0.064), and based on the average flow properties within the mixing stack and the hydraulic diameter of the mixing stack, the air flow through the eductor system is turbulent ($Re>10^5$). As a consequence of this, momentum exchange is predominant over shear interaction, and the kinetic and internal energy terms are more influential on the flow than are viscous forces. It can also be shown that the Mach number represents the ratio of kinetic energy of a flow to its internal energy and is, therefore, a more significant parameter than the Reynolds number in describing the primary flow through the uptakes.

## B. ONE-DIMENSIONAL ANALYSIS OF A SIMPLE EDUCTOR

The theoretical analysis of an eductor may be approached in two ways. One method attempts to analyze the details of the mixing process of the primary and secondary air streams as it takes place inside the mixing stack. This requires an interpretation of the mixing phenomenon which, when applied to a multiple nozzle system, becomes extremely complex. The other method, which was chosen here, analyzes the overall performance of the eductor system and is not concerned with the actual mixing process. The one-dimensional analysis

based on a single primary nozzle exhausting into a mixing stack, as shown in Figure A-1. To avoid repetition with previous reports, only the main parameters and assumption will be represented here. A complete derivation of analysis used can be found in References [1] and [4]. The one-dimensional flow analysis of the simple eductor system described depends on the simultaneous solution of the continuity, momentum and energy equations coupled with the equation of state, all compatible with specific boundary conditions.

The idealizations made for simplifying the analysis are as follows:

1. The flow is steady state and incompressible.
2. Adiabatic flow exists throughout the eductor with isentropic flow of the secondary stream from the plenum (at section 0) to the throat or entrance of the mixing stack (at section 1) and irreversible adiabatic mixing of the primary and secondary streams occurs in the mixing stack (between sections 1 and 2).
3. The static pressure across the flow at the entrance and exit planes of the mixing-tube (at sections 1 and 2) is uniform.
4. At the mixing-stack entrance (section 1) the primary flow velocity $U_p$ and temperature $T_p$ are uniform across the primary stream, and the secondary flow velocity $U_s$ and temperature $T_s$ are uniform across

the secondary stream, but $U_p$ does not equal $U_s$, and $T_p$ does not equal $T_s$.

5. Incomplete mixing of the primary and secondary streams in the mixing stack is accounted for by the use of a non-dimensional momentum correction factor $K_m$ which relates the actual momentum rate to the pseudo-rate based on the bulk-average velocity and density and by the use of a non-dimensional kinetic energy correction factor $K_e$ which relates the actual kinetic energy rate to the pseudo-rate based on the bulk-average velocity and density.
6. Both gas flows behave as perfect gases.
7. Flow potential energy position changes are negligible.
8. Pressure changes $P_{s0}$ to $P_{s1}$ and $P_1$ to $P_a$ are small relative to the static pressure so that the gas density is essentially dependent upon temperature (and atmospheric pressure).
9. Wall friction in the mixing stack is accounted for with the convectional pipe friction factor term based on the bulk-average flow velocity $U_m$ and the mixing stack wall area $A_w$.

The following parameter, defined here for clarity, will be used in the following development.

$\frac{A_p}{A_m}$ area ratio of primary flow area to mixing stack cross sectional area

$\frac{A_w}{A_m}$ area ratio of wall friction area to mixing stack cross sectional area

$k_p$ momentum correction factor for primary mixing

$K_m$ momentum correction factor for mixed flow

$f$ wall friction factor

Base on the continuity equation, the conservation of mass principle for steady flow yields

$$W_m = W_p + W_s + W_t \tag{1}$$

where

$$\begin{aligned} W_p &= \rho_p U_p A_p \\ W_s &= \rho_s U_s A_s \\ W_t &= \rho_t U_t A_t \\ W_m &= \rho_m U_m A_m \end{aligned} \tag{1a}$$

All of the above velocity and density terms, with the exception of $\rho_m$ and $U_m$, are defined without ambiguity by the virtue of idealizations (3) and (4) above. Combining equations (1) and (1a) above, the bulk average velocity at the exit plane of the mixing stack becomes

$$U_m = \frac{W_s + W_t + W_p}{\rho_m A_m} \tag{1b}$$

where $A_m$ is fixed by the geometric configuration and

$$\rho_m = \frac{p_a}{RT_m} \tag{2}$$

where $T_m$ is calculated as the bulk average temperature from the energy equation (9) below. The momentum equation stems

from Newton's second and third laws of motion and is the conventional force and momentum-rate balance in fluid mechanics.

$$K_p\left(\frac{W_p U_p}{g_c}\right) + \left(\frac{W_s U_s}{g_c}\right) + \left(\frac{W_t U_t}{g_c}\right) + P_1 A_1 = K_m\left(\frac{W_m U_m}{g_c}\right) + P_2 A_2 + F_{fr} \quad (3)$$

Note the introduction of idealizations (3) and (5). To account for a possible non-uniform velocity profiles across the primary nozzle exit, the momentum correction factor $K_p$ is introduced here. It is defined in a manner similar to that of $K_m$ and by idealization (4), supported by work conducted by Moss, it is set equal to unity. $K_p$ is carried through this analysis only to illustrate its effect on the final result. The momentum correction factor for the mixing stack exit is defined by the relation

$$K_m = \frac{1}{W_m U_m} \int_0^{A_m} U_m^2 \rho_2 dA \quad (4)$$

where $U_m$ is evaluated as the bulk-average velocity from equation (1b). The wall skin friction force $F_{fr}$ can be related to the flow stream velocity by

$$F_{fr} = f A_w\left(\frac{U_m^2 \rho_m}{2 g_c}\right) \quad (5)$$

using idealization (9). As a reasonably good approximation for turbulent flow, the friction factor may be calculated from the Reynolds number

$$f = 0.046(Re_m)^{-0.2}. \tag{6}$$

Applying the conservation of energy principle to the steady flow system in the mixing stack between the entrance and exit planes,

$$W_p\left(h_p + \frac{U_p^2}{2g_c}\right) + W_s\left(h_s + \frac{U_s^2}{2g_c}\right) + W_t\left(h_t + \frac{U_t^2}{2g_c}\right)$$

$$= W_m\left(h_m + K_e\frac{U_m^2}{2g_c}\right) \tag{7}$$

neglecting potential energy of position changes (idealization 7). Note the introduction of the kinetic energy correction factor $K_e$, which is defined by the relation

$$K_e = \frac{1}{W_m U_m^2}\int_0^{A_m} U_2^3 \rho_2 \, dA \tag{8}$$

It may be demonstrated that for the purpose of evaluating the mixed mean flow temperature $T_m$, the kinetic energy terms may be neglected to yield

$$h_m = \frac{W_p}{W_m} h_p + \frac{W_s}{W_m} h_s + \frac{W_t}{W_m} h_t \tag{9}$$

where $T_m = \phi(h_m)$ only, with the idealization (6).

The energy equation for the isentropic flow of the secondary air from the plenum to the entrance of the mixing stack may be shown to reduce to

$$\frac{P_o - P_s}{\rho_s} = \frac{U_s^2}{2g_s} \tag{10}$$

similarly, the energy equation for the tertiary air flow reduces to

$$\frac{P_o - P_t}{\rho_t} = \frac{U_t^2}{2g_c}$$

The forgoing equations may be combined to yield the vacuum produced by the eductor action in either the secondary or tertiary air plenums. For the secondary air plenum, the vacuum produced is

$$P_a - P_{os} = \frac{1}{g_c A_m}\left(K_p \frac{W_p^2}{A_p \rho_p} + \frac{W_s^2}{A_s \rho_s}\left(1 - \frac{1}{2}\frac{A_m}{A_s}\right) - \frac{W_m^2}{A_m \rho_m}\left(K_m + \frac{f}{2}\frac{A_w}{A_m}\right)\right) \tag{11}$$

where it is understood that $A_p$ and $\rho_s$ apply to the secondary flow at this same section, and $A_m$ and $_m$ apply to the mixed flow at the exit of the mixing stack system. $P_a$ is atmospheric pressure, and is equal to the pressure at the exit of the mixing stack. $A_w$ is the area of the inside wall of the mixing stack.

For the tertiary air plenum, the vacuum produced is

$$P_a - P_{ot} = \frac{1}{g_c A_m}\left(k_p\left(\frac{(W_p+W_s)^2}{A_p \rho_p + A_s \rho_s}\right) + \frac{W_t^2}{A_t \rho_t}\left(1 - \frac{1}{2}\frac{A_m}{A_t}\right)\right.$$

$$\left. = \frac{W_m^2}{A_m \rho_m}\left(K_m + \frac{f}{2}\frac{A_w}{A_m}\right)\right) \tag{11a}$$

where the primary flow now consists of both the primary and secondary air flows.

C. NON-DIMENSIONAL FORM OF THE SIMPLE EDUCTOR EQUATION

In order to provide the criteria of similarity of flows with geometric similarity, the non-dimensional parameters which givern the flow must be determined. The means chosen for determining these parameters is to normalize equations (11) and (11a) with the following dimensionless groupings.

$$\Delta P^* = \frac{P_a - P_{os}}{\frac{\rho_s U_p^2}{2g_c}}$$

a pressure coefficient which compares the pumped head $P_a - P_{os}$ for the secondary flow to the driving head $\frac{U_p^2}{2g_c}$ of the primary flow

$$\Delta PT^* = \frac{P_a - P_{ot}}{\frac{\rho_t U_p^2}{2g_c}}$$

a pressure coefficient which compares the pumped head $P_a - P_{os}$ for the tertiary flow to the driving head $\frac{U_p^2}{2g_c}$ of the primary flow

$$W^* = \frac{W_s}{W_p}$$

a flow rate ratio, secondary to primary mass flow rate

$$WT^* = \frac{W_t}{W_p}$$

a flow rate ratio, tertiary to primary mass flow rate

$$T^* = \frac{T_s}{T_p}$$

an absolute temperature ratio, secondary to primary

$$TT^* = \frac{T_t}{T_p}$$

an absolute temperature ratio, tertiary to primary

$$\rho_s^* = \frac{\rho_s}{p}$$

a flow density ratio of the secondary to primary flows. (note that since the fluids are considered perfect gases,

$$\rho_s^* = \frac{T_p}{T_s} = \frac{1}{T_s^*})$$

$\rho_t^* = \frac{\rho_t}{p}$ a flow density ratio of the tertiary or film cooling flow to primary flows. (Note that since the fluids are considered perfect gases,

$$\rho_t^* = \frac{T_p}{T_t} = \frac{1}{T_t^*})$$

$A_s^* = \frac{A_s}{A_p}$ an area ratio of secondary flow area to primary flow area

$A_t^* = \frac{A_t}{A_p}$ an area ratio of tertiary flow area to primary flow area

With these non-dimensional groupings, equations (11) and (11a) can be rewritten in dimensionless form. Since both equations follow the same format, only the results for the secondary air plenum will be presented here.

$$\frac{\Delta P^*}{T^*} = 2\,\frac{A_p}{A_m}\left(\left(K_p - \frac{A_p}{A_m}\,\beta\right) - W^*(K_p + T^*)\,\frac{A_p}{A_m}\,\beta + W^{*2}T^*\left(\frac{1}{A^*}\left(K_p - \frac{A_m}{2A^*A_p}\right) - \frac{A_p}{A_m}\,\beta\right)\right) \qquad (12)$$

where

$$\beta = K_m + \frac{f}{2}\,\frac{A_w}{A_m}\,.$$

This may be rewritten as

$$\frac{P^*}{T^*} = C_1 + C_2W^*(T + 1) + C_3W^{*2}T^* \qquad (13)$$

where

$$C_1 = 2\frac{A_p}{A_m}\left(K_p - \frac{A_p}{A_m}\beta\right),$$

$$C_2 = -2\left(\frac{A_p}{A_n}\right)^2\beta, \text{ and}$$

$$C_3 = 2\frac{A_p}{A_m}\left(\frac{1}{A^*} - \frac{A_m}{2A^*A_p}\beta - \frac{A_p}{A_m}\beta\right) .$$

As can be ssen from equation (13),

$$\Delta P^* = F(W^*, T^*).$$

The additional dimensionless quantitites listed below were used to correlate the static pressure distribution down the length of the mixing stack.

$$PMS^* = \frac{\frac{PMS}{\rho_s}}{\frac{U_p^2}{2g_c}}$$

a pressure coefficient which compares the pumping head $\frac{PMS}{\rho_s}$ for the secondary flow to the driving head $\frac{U_p^2}{2g_c}$ of the primary flow, where PMS = static pressure along the mixing stack length

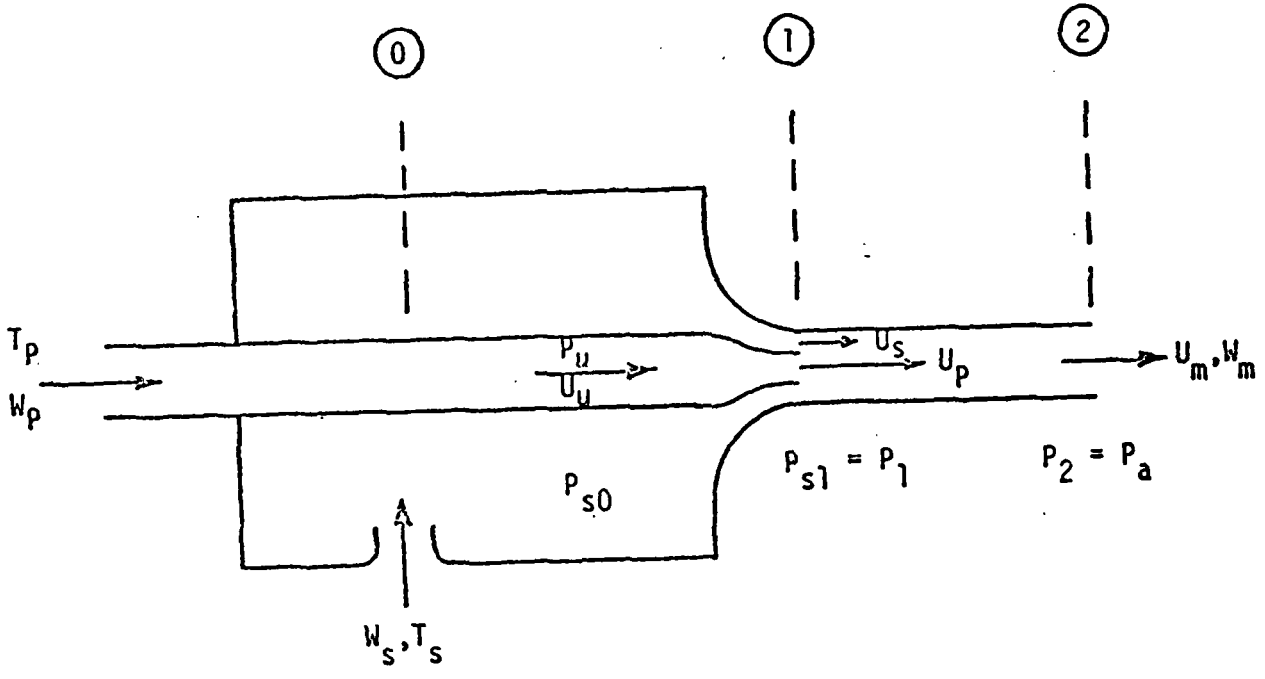



FIGURE A-I. SIMPLE SINGLE NOZZLE EDUCTOR SYSTEM

## APPENDIX: B

## FORMULA

Presented here are the fomulas used to obain the primary and secondary mass flow rates. According to the ASME Power Test Code (5), the general equation for mass flow rate appearing in equation (a)

$$W(\text{lbm/sec}) = (0.12705)\ K\ A\ Y\ F_a\ (\rho\ \Delta P)^{0.5} \qquad (a)$$

may be used with flow nozzles and square edge orifices provided the flow is subsonic. In the above equation, K (dimensionless) represents the flow coefficient for the metering device and is defined as $K = C(1 - \beta^4)^{-0.5}$ where C is the coefficient of discharge and $\beta$ is the ratio of throat to inlet diameters; $A(in^2)$ is the total cross sectional area of the metering device; Y (dimensionless) is the expansion factor for the flow; $F_a$ (dimensionless) is the area thermal expansion factor; $\rho$ ($lbm/ft^3$) is the flow mass density; and $\Delta P$ (inches $H_2O$) is the differential pressure across the metering device. Each of these quantitites are evaluated, according to the guidelines set forth in Reference [5], for the specific type of flow measuring device used.

Using a square edge orifice for measurement of the primary mass flow rate, the quantities in equation (a) are defined as follows:

1. The flow coefficient K is 0.62 based on a $\beta$ of 0.502 and a constant coefficient of discharge over the range of flows considered of 0.60.
2. The orifice area is 37.4145 $in^2$.
3. Corresponding to the range of pressure ratios encountered across the orifice, the expansion factor Y is 0.98.
4. Since the temperature of the metered air is nearly ambient temperature, thermal expansion factor is essentially 1.0.
5. The primary air mass density $\rho_{or}$ is calculated using the perfect gas relationship with pressure and temperature evaluated upstream of the orifice.

Substituting these values into equation (a) yields

$$W_p \text{ (lbm/sec)} = (2.8882) (\rho_{or} \Delta P_{or})^{0.5} \qquad \text{(b)}$$

The secondary mass flow rate is measured using long radius flow nozzles for which case the quantities in equation (a) becomes:

1. For a flow nozzle installed in a plenum, $\beta$ is approximately zero in which case the flow coefficient is approximately equal to the coefficient of discharge. For the range of secondary flows encountered, the flow coefficient becomes 0.98.
2. A is the sum of the throat areas of the flow nozzles in use.

3. Since the pressure ratios across the flow nozzles are very close to unity, the expansion coefficient Y is 1.0.

4. Since the temperature of the metered air is nearly ambient temperature, the thermal expansion factor is essentially 1.0.

5. The secondary air mass density $\rho_s$ is evaluated using the perfect gas relationship at ambient conditions.

Substituting these values into equation (a) yields the equation for the secondary mass flow rate measured using long radius flow nozzles.

$$W_s \text{ (lbm/sec)} = (0.13451)\ A\ (\rho_s \Delta P_s)^{0.5} \qquad \text{(c)}$$

## APPENDIX: C

## DATA ACQUISITION AUTOMATION

The method used in taking data with this and previous theses has been completely manual. Although the procedure has been adequate, it has been combersome. An ancillary objective of this thesis has been to assemble a system to automatically collect, reduce ans store the data required.

The system developed utilizes the following equipment:

1) Hewlett Packard Model 85 Computer
2) Hewlett Packard Model 82901M Flexible Disc Drive
3) Hewlett Packard Model 7225-A Plotter
4) Hewlett Packard Model 3497A *Data Acquisition/* Control Unit.

These equipments were connected via a Hewlett Packard Model 82937A Interface Bus. Additionally, the HP-85 had installed the Mass Storages, Plotter/Printer, and Matrix ROMS (Read Only Memories). Figures C-I and C-II show a system schematic and the actual equipment used.

Pressure reading were taken with poly-flo tubing from the scanivalve via a manifold arrangement to Validyne Model DP 103 pressure transducers. Two transducers are utilized, one with a pressure range of 0 to 5.5 inches of $H_2O$ (0-0.2 psi), the other with a pressure range of 0 to 35 inches of

$H_2O$ (0-1.2 psi). The DC electrical signal from the transducer is amplified through a Validyne CD10 Carrier Demodulator. The carrier demodulator also provides controls for setting the zero point of the transducer and varying the span of the voltage output from the unit. The DC output from the demodulator is measured by the voltmeter within the HP-3497A data acquisition unit. The 3497A transmits the voltage value to the HP-85 where a subroutine of the acquisition program converts the voltage to a pressure value.

Temperature readings are taken in a similar manner. The thermocouple voltages are read directly bu the 3497A data acquisition unit. A different subroutine within the data acquisition program converts the voltage reading to temperature values.

The conversion formula for temperature was derived from reference tables for type T copper-constantan thermocouples. Voltages from the reference table at ten degree increments from 0 to 120 degrees Fahrenheit were input into a program from the HP-85 Math Pac. This program provided the coefficients for a degree Chebyshev polynomial. The following formula results:

$$T = .0608773(V)^3 - 1.289098(V)^2 + 46.58608(V) + 32.00443$$

where T is degrees Fahrenheit and V is millivolts.

Unlike the thermocouple, calibration of the transducers must be accomplished everytime the equipment is energized. This is because the location of the zero point is not always

constant. Calibration of the transducers required use of the building air supply. The compressor in the building is a Worthington Air Compressor set at a nominal operating pressure of 100 psig. Sufficient air pressure was obtained by regulating the supply valve from the building air system and installing a throttling valve prior to a manifold. Both the pressure transducers and a 20 inch water manometer are connected to the manifold. In addition an exhaust valve that can be throttled is also attached to the manifold. With the building air supply completely disconnected and all manifold valves open, the zero point is set. The air supply is then connected to the manifold and the pressure is raised to 5.0 or 20 inches of water depending on the transducer to be calibrated. A vacuum can be obtained by inserting a tee fitting into the poly-flo tubing ahead of the inlet throttling valve. This forms an eductor that takes a suction on the manifold. By varying the building air supply valve and the throttle valves connected to the manifold the desired vacuum can be reached. When calibrating the 0 to 35 inch transducer it is vital that the valve isolating the lower range transducer be secured. An additional safety precaution is to have a vent valve installed between the manifold and the transducer. This safety valve is to be open whenever the 5.5 inch transducer is not in use. After raising the pressure to the high end calibration point the pressure is trapped in the manifold by closing all valves. A transducer reading is

then taken and recorded with the pressure reading from the manometer. The process is then repeated with several values ath the low end of the pressure range. These voltages and corresponding pressure values are then inputed into the Chebyshev polynomial program and the coefficients for a 1st degree euqation are obtained. These coefficients are then inserted into the data acquisition program.

It is important to note that the transducer can be set for reading either positive or negative differential pressure. Once a transducer has been calibrated for the desired positive or negative range measuring a pressure of the opposite sign will cause the zero point of the transducer to shift. Recalibration will then be required. Because both positive and negative differential pressures were measured it was found that one transducer had to be calibrated for pressures less than atmospheric and one for pressures greater than atmospheric. A Sample calibration program is included in Table C-I.

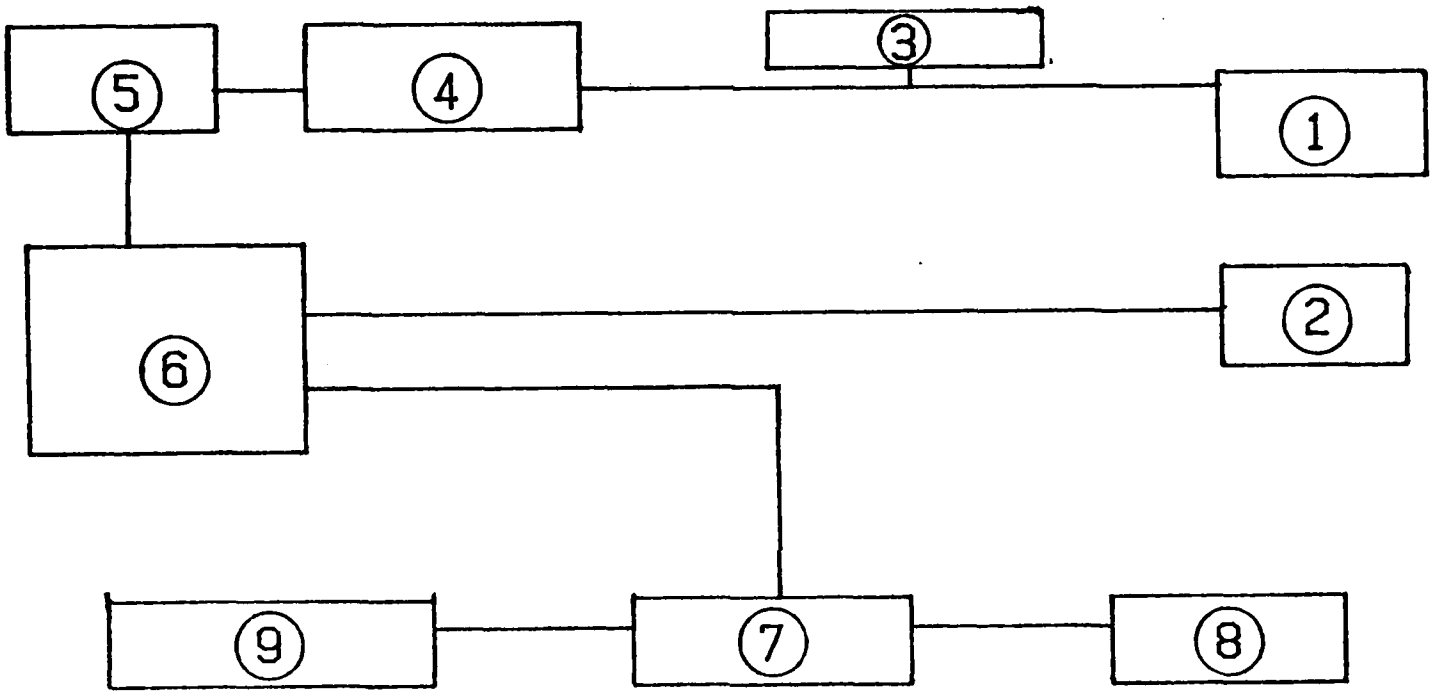
Once the calibration process is complete the data acquisition program is run. This program will record the required pressures and temperatures and upon completion store the values under the desired filename on the flexible disc. The data reduction program is then loaded from the disc storage and executed. Upon completion of the data reduction program, plot programs are called which will provide output on the 7225-A Plotter.

The data acquisition system as presently configured is semi-automatic. Temperatures can be automatically taken in sequence but the program must stop and allow the operator to manually step the scanivalve and arrange the valving for the correct transducer. The use of a digital stepping device would further automate the process. Additionally, a transducer dedicated to only determining positive or negative differential pressure and electrically operated manifold valves would complete the process.

Even though the system is not yet completely automatic. the ability to reduce data on site provides more flexibility and ease of conducting the thesis research.

```
10 ! The name of this program
   is CAL35XD.
20 OPTION BASE 0
30 DISP "This program is design
   ed to"
40 DISP "calibrate the 0-35 in
   trans-"
50 DISP "ducer.It will give you
    values"
60 DISP "to input into the CHEB
   Y pro-"
70 DISP "gram to get coefficien
   ts for a"
80 DISP "calibration function.M
   ake sure"
90 DISP "that the 5.5 in transd
   ucer is"
100 DISP "DISCONNECTED from the
   manifold."
110 DIM X(4,1)
120 DISP "With the 35 in transdu
   cer dis-"
130 DISP "connected at the manif
   old,set"
140 DISP "the zero point on the
   carrier"
150 DISP "demodulator."
160 OUTPUT 709 ;"VR5ARAC3SA"
170 DISP "Press CONT when ready.
   "
180 PAUSE
190 DISP "Reconnect transducer t
   o the"
200 DISP "manifold.When air pres
   sure is"
210 DISP "set at 20 in H20 press
    CONT."
220 PAUSE
230 I=20
240 FOR J=4 TO 0 STEP -1
250 X(J,0)=I
260 OUTPUT 709 ;"VR5AI3SA"
270 ENTER 709 ; X(J,1)
280 OUTPUT 709 ;"ARAC3"
290 DISA X(J,0),X(J,1)
300 I=I-5
310 DISP "Decrement IN H20 by 5
   IN to ";I
320 IF J=0 THEN 340
330 PAUSE
340 NEXT J
350 DISP "  P       V"
360 DISP "inH20 voltage"
370 MAT DISP X;
380 DISP "HARD COPY(1=yes 2=no)"
   ;
390 INPUT N
400 IF N#1 THEN 440
410 PRINT "  P       V"
420 PRINT "inH20 voltage"
430 MAT PRINT X
440 END
```

TABLE C-I. SAMPLE CALIBRATION PROGRAM




① SCANIVALVE
② THERMOCOUPLES
③ MANOMETER
④ TRANSDUCERS
⑤ CARRIER DEMODULATOR
⑥ DATA ACQUISITION UNIT
⑦ COMPUTER
⑧ PLOTTER
⑧ FLEXIBLE DISC STORAGE

FIGURE C-I. SCHEMATIC OF DATA ACQUISITION SYSTEM

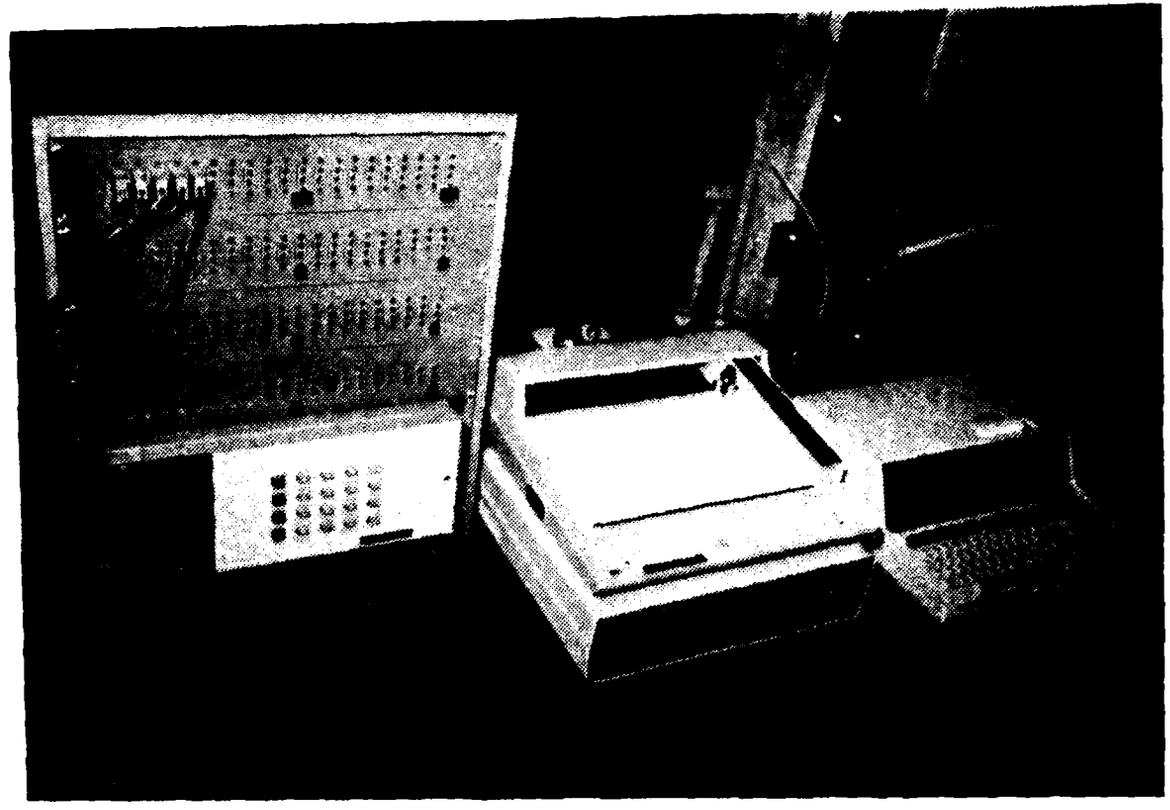


FIGURE C-IIa. ILLUSTRATION OF DATA ACQUISITION SYSTEM

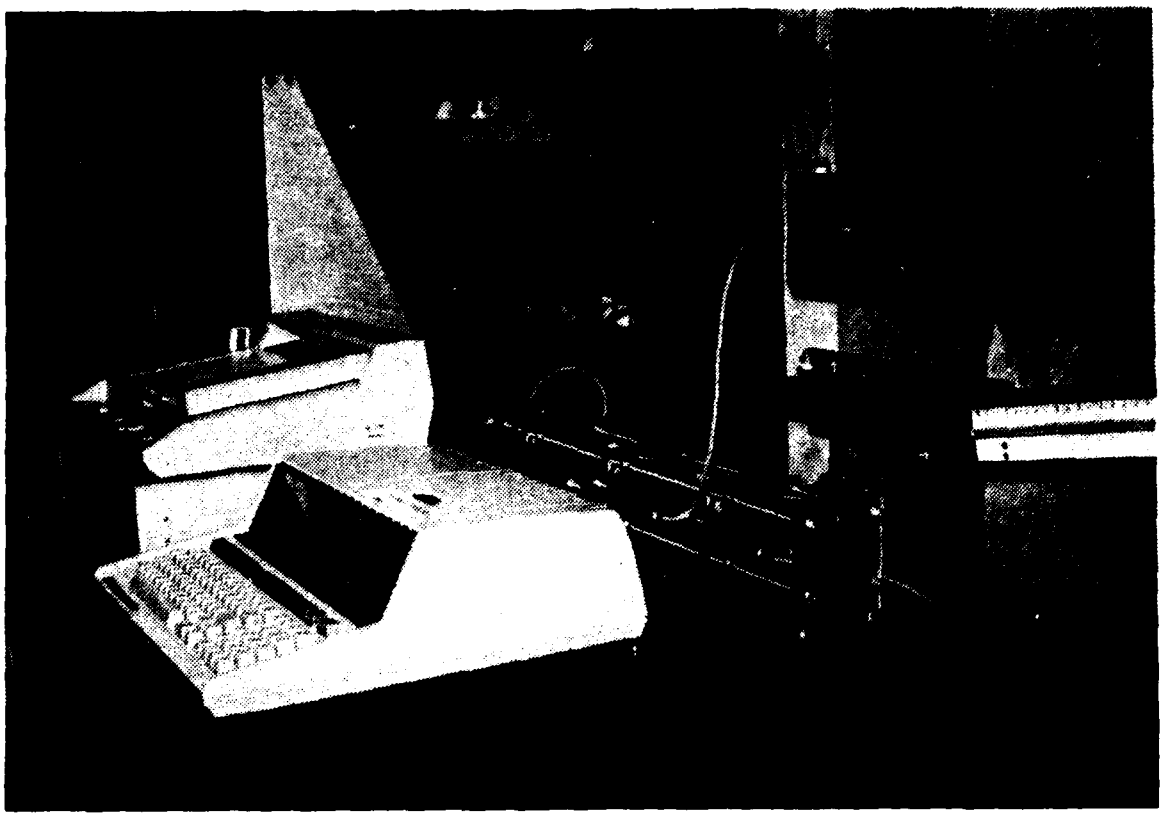


FIGURE C-IIb. ILLUSTRATION OF DATA ACQUISITION SYSTEM

## APPENDIX: D

## UNCERTAINTY ANALYSIS

The determination of the uncertainties in the experimentally determined pressure coefficients, pumping coefficients, and velocity profiles was made using the method described by Kline and McClintock [6]. The uncertainties obtained by Ellin [1] using the second order equation suggested by Kline and McClintock [6] are all applicable to the experimental work reported herein and are summarized in the following table.

### TABLE XIV

### UNCERTAINTY IN MEASURED VALUES

| | |
|---|---|
| $T_s$ | ± 1 R |
| $T_p$ | ± 1 R |
| $P_a$ | ± 0.01 psia |
| $\Delta P$ | ± 0.01 in. $H_2O$ |
| $P_V$ | ± 0.01 in. $H_2O$ |
| $P_u$ | ± 0.05 in. $H_2O$ |
| $\Delta P_s$(+) | ± 0.01 in. $H_2O$ |
| $\Delta P_t$(**) | ± 0.01 in. $H_2O$ |
| $P_{or}$ | ± 0.01 in. $H_2O$ |
| $\Delta P_{or}$ | ± 0.20 in. $H_2O$ |

| | |
|---|---|
| $T_{or}$ | ± 1 R |
| $T_a$ | ± 1 R |
| PT (+++) | ± 0.1 in. $H_2O$ |

UNCERTAINTY IN CALCULATED VALUES

| | |
|---|---|
| $\frac{AP^*}{T^*}$ | 1.9% |
| $W^*T^{*0.44}$ | 1.4% |
| $V/V_{avg}$ | 2.5% |

(+) The pressure differential across the secondary flow nozzles, $P_s$, is the major source of uncertainty in the pumping coefficient.

(++) The pressure differential across the tertiary flow nozzles, $P_t$, is the major source of uncertainty in the pumping coefficient.

(+++) The measurement of the total pressure for the velocity profile is the major source of uncertainty in the velocity calculation.

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